6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.2 IN-LINE VALVES AND PUMPS

This category covers equipment that is in-line with pressure piping. These items may be valves or pumps and may be suspended, floor-mounted, roof-mounted, or wall-mounted. They may be mounted with or without vibration isolation.

TYPICAL CAUSES OF DAMAGE

- Poorly restrained in-line valves or equipment may fall. Pumps may be damaged if not properly restrained; these items may slide or fall. Movement of the in-line equipment may result in damage to the attached piping at the connection or at adjacent pipe joints. Equipment or piping damage may result in leaks.

SEISMIC MITIGATION CONSIDERATIONS

- Details shown are for overhead restraints for items in-line with suspended piping. Generally, seismic restraint in the form of typical pipe bracing is provided on each side of the connected item.
- Details for other conditions such as equipment in-line with floor- or wall-mounted piping can be found in FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004). Section 6.4.1.5 also includes general details for suspended equipment.
- Many vendors supply specialized hardware for seismic anchorage of piping including load rated anchorage assemblies, spring loaded hangers, and pipe dampers.

Mitigation Examples

Figure 6.4.3.2-1 Inline pump mounted on independent concrete inertia pad with vibration isolation and seismic snubbers (Photo courtesy of Mason Industries).

Mitigation Details

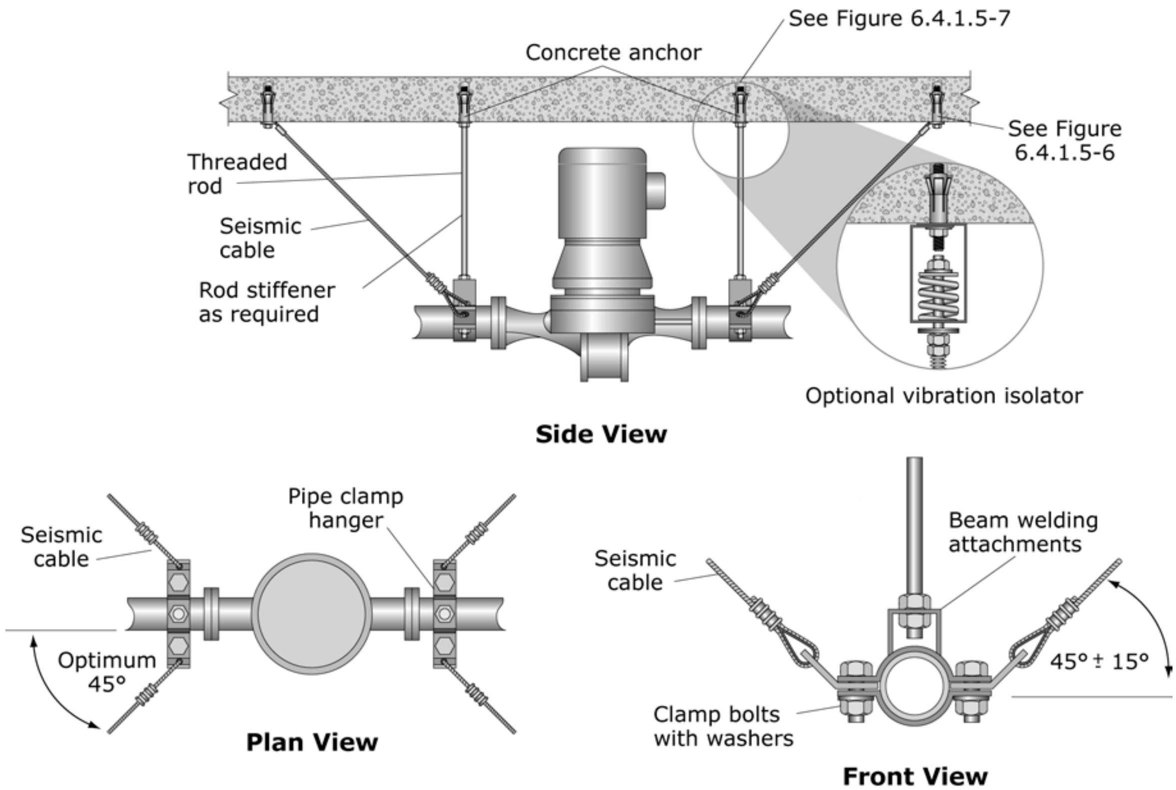


Figure 6.4.3.2-2 In-line valves and pumps (ER).

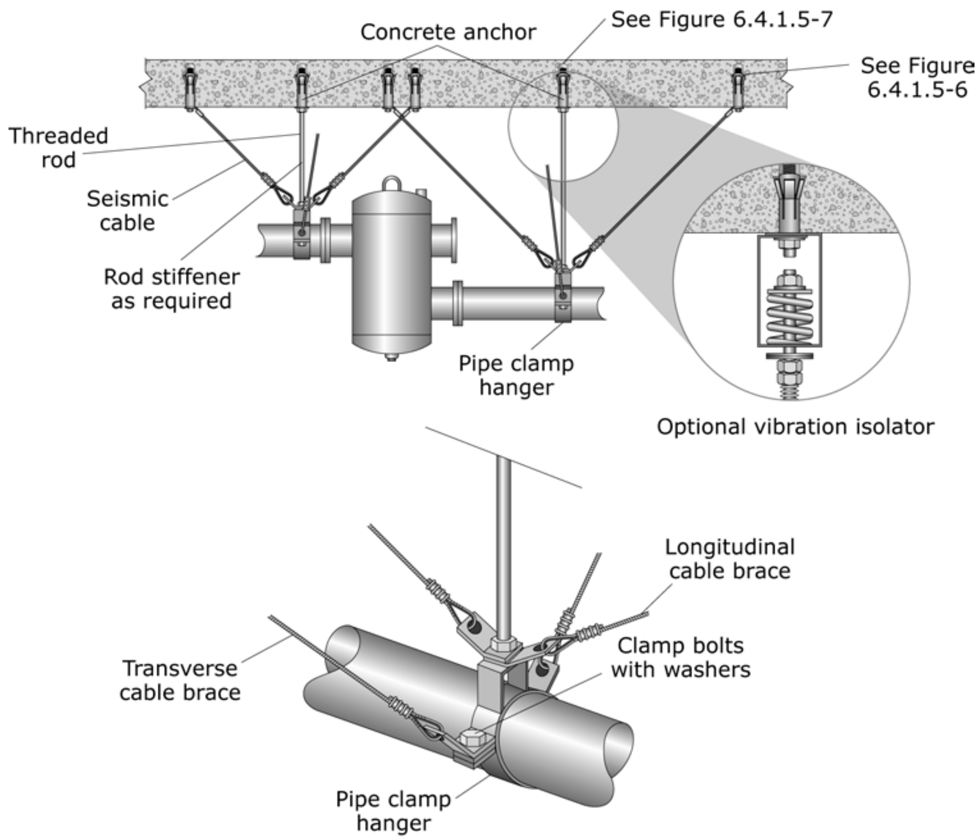


Figure 6.4.3.2-3 In-line valves and pumps (ER).

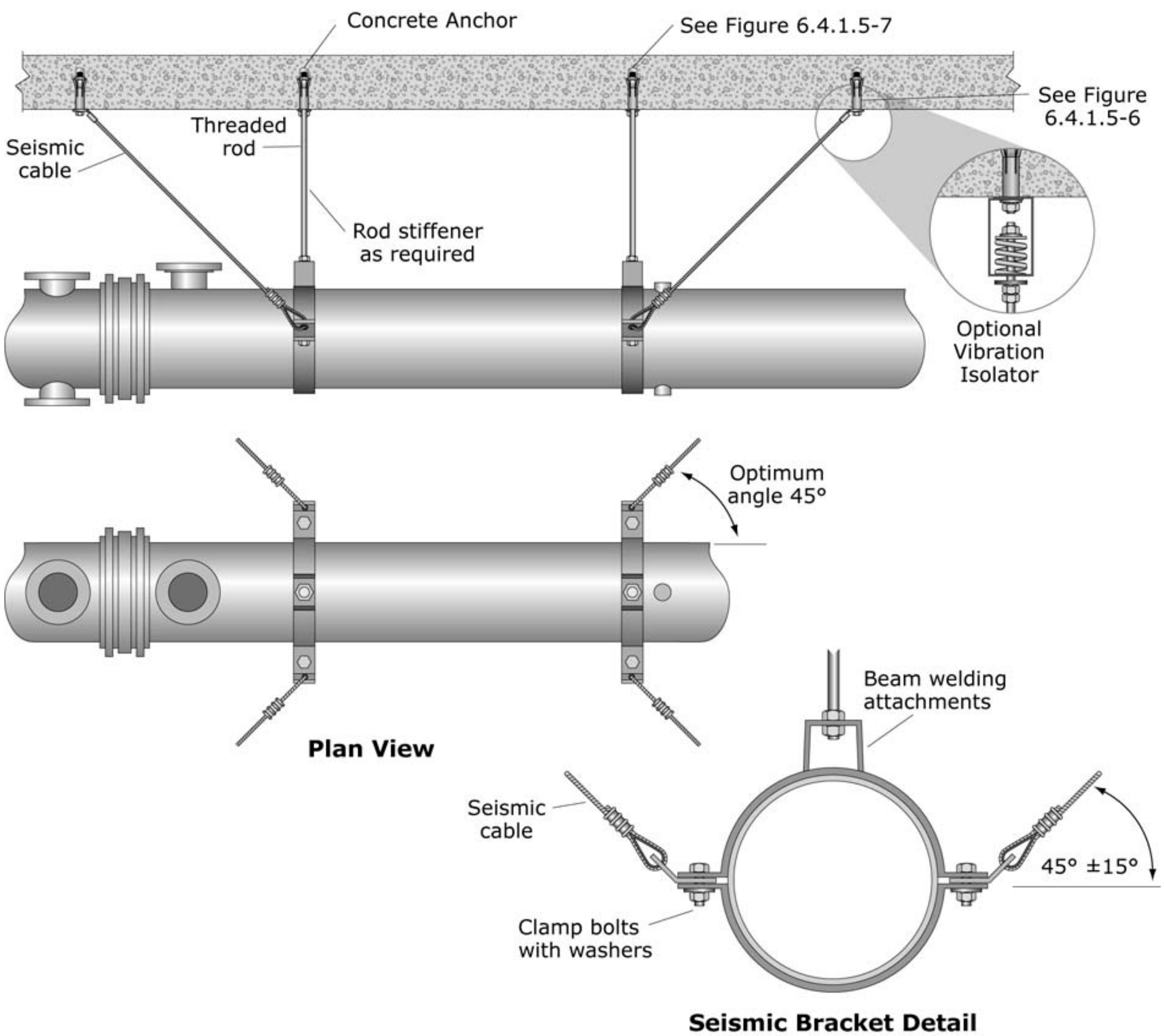


Figure 6.4.3.2-4 In-line valves and pumps (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.3 FLEXIBLE CONNECTIONS, EXPANSION JOINTS, AND SEISMIC SEPARATIONS

This category covers the flexible piping connections required to accommodate differential movement at seismic separations between buildings or between floors, at the interface between piping and equipment, or to accommodate thermal expansion.

TYPICAL CAUSES OF DAMAGE

- Differential movement between adjacent buildings or adjacent wings of buildings can cause damage to interconnected piping if relative movement has not been specifically accounted for. Differential movement between the fixed and base isolated portions of buildings can damage piping crossing the isolation plane. Failure to accommodate seismic displacements can rupture piping.
- Differential movement between anchored or restrained equipment and attached piping can cause damage to the equipment, the piping, or both.

Damage Examples

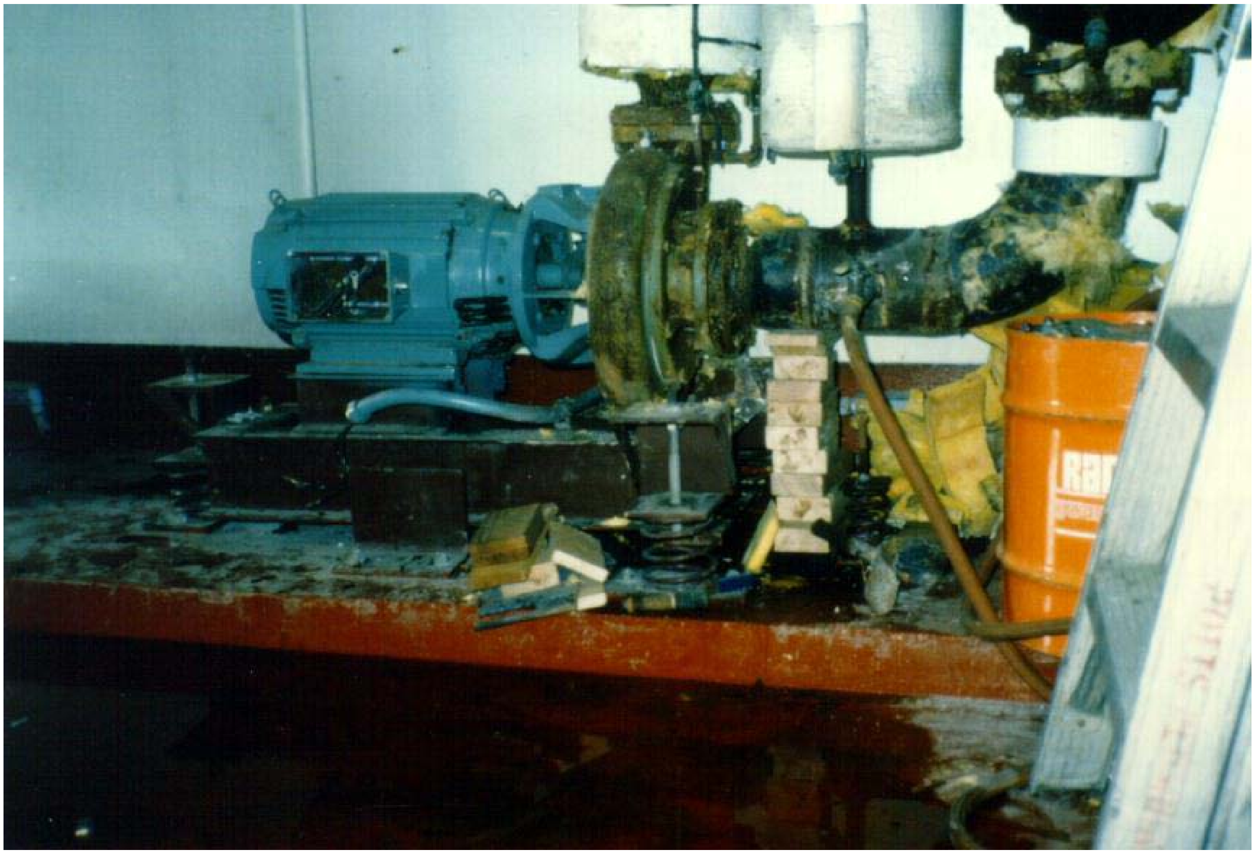


Figure 6.4.3.3-1 Failure at rigid connection to equipment on isolators without lateral restraint in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

SEISMIC MITIGATION CONSIDERATIONS

- Flexible couplings are needed to accommodate relative displacement in a pipeline. Locations that may require flexible couplings include connections between piping and anchored equipment, wall or slab penetrations, seismic joints between buildings, and seismic joints in base isolated buildings. Selection of a specific coupling detail will depend on the magnitude of the anticipated relative displacements, the diameter of the pipe, and the type of pipe and its location.
- Several different types of flexible connections are shown; details for other conditions including floor and roof penetrations can be found in FEMA 414 *Installing Seismic Restraints for Duct and Pipe* (2004). Many vendors supply specialized hardware to create articulated joints or flexible tubing for these applications.
- Connections must provide sufficient flexibility to accommodate the expected differential movement in all directions.
- It is generally good seismic resistant design practice to provide a flexible connection between piping and equipment.

Mitigation Examples

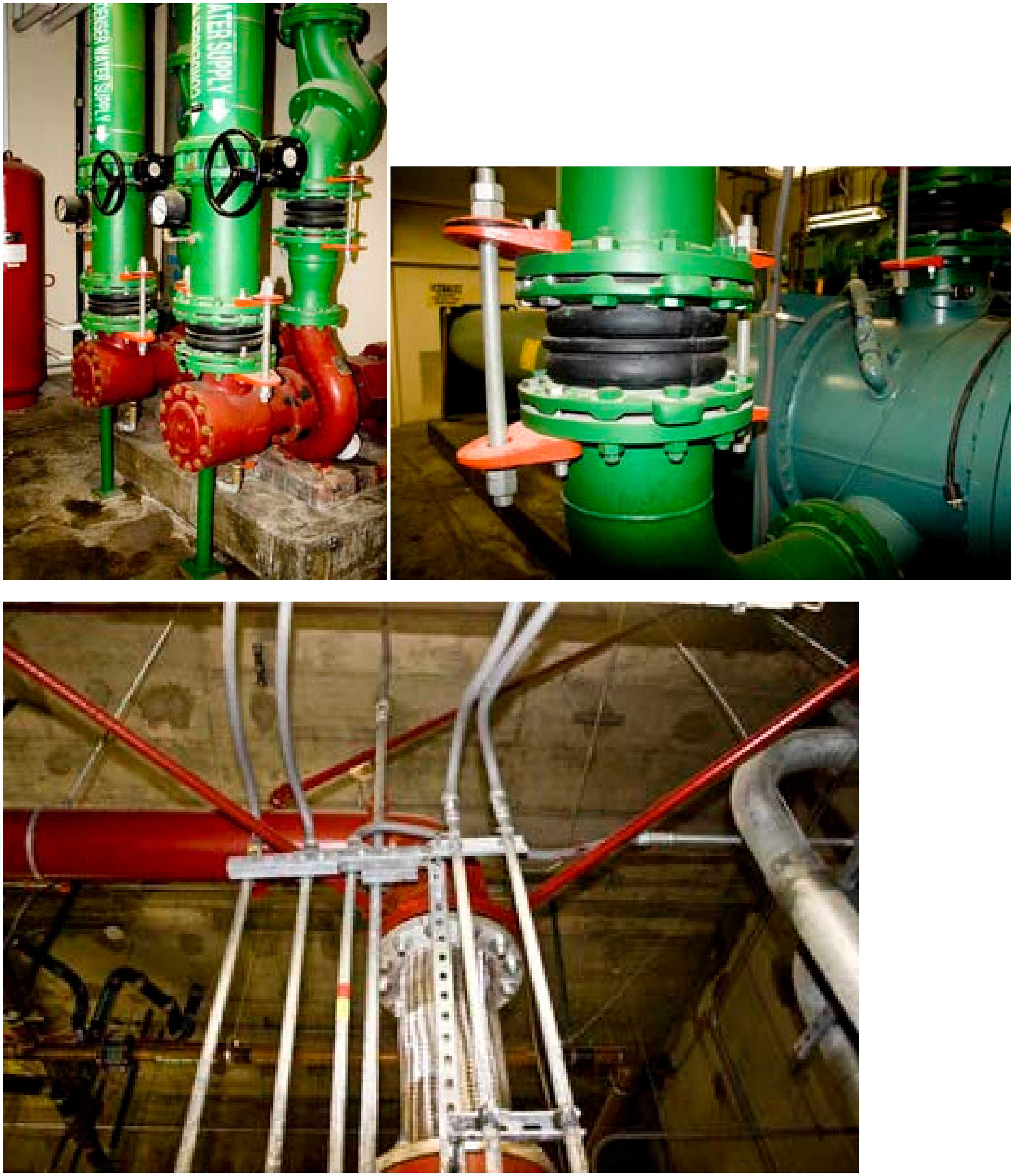


Figure 6.4.3.3-2 Examples of flexible couplings that performed well in the 2010 magnitude-7 Haiti Earthquake; the building suffered relatively minor damage (Photo courtesy of Tom Sawyer, Engineering News Record).

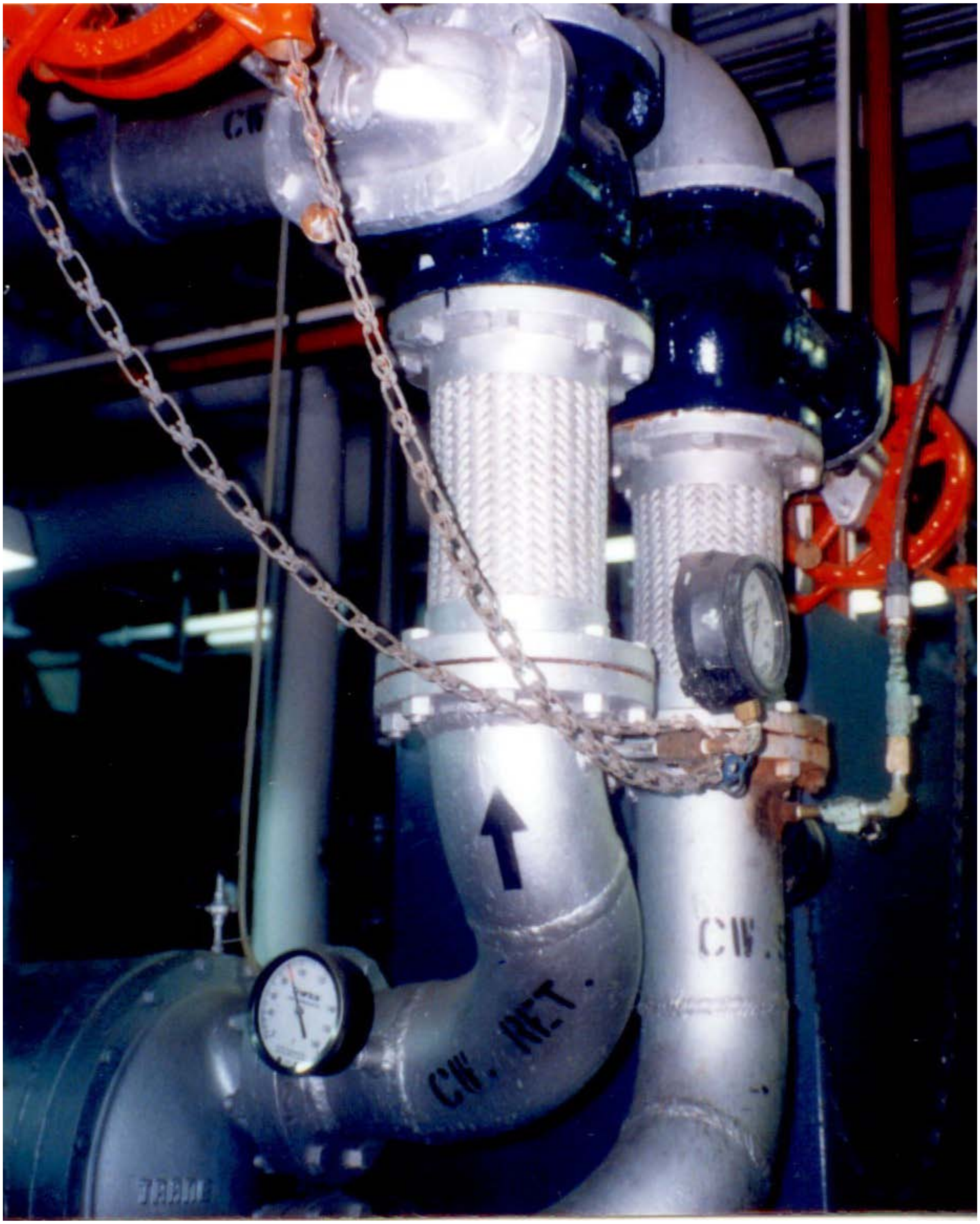


Figure 6.4.3.3-3 Flexible connection at pipe attachment to rigidly mounted tank (Photo courtesy of Wiss, Janney, Elstner, Associates).

Figure 6.4.3.3-4 Flexible pipe connections at rooftop expansion joint (Photo courtesy of Maryann Phipps, Estructure).

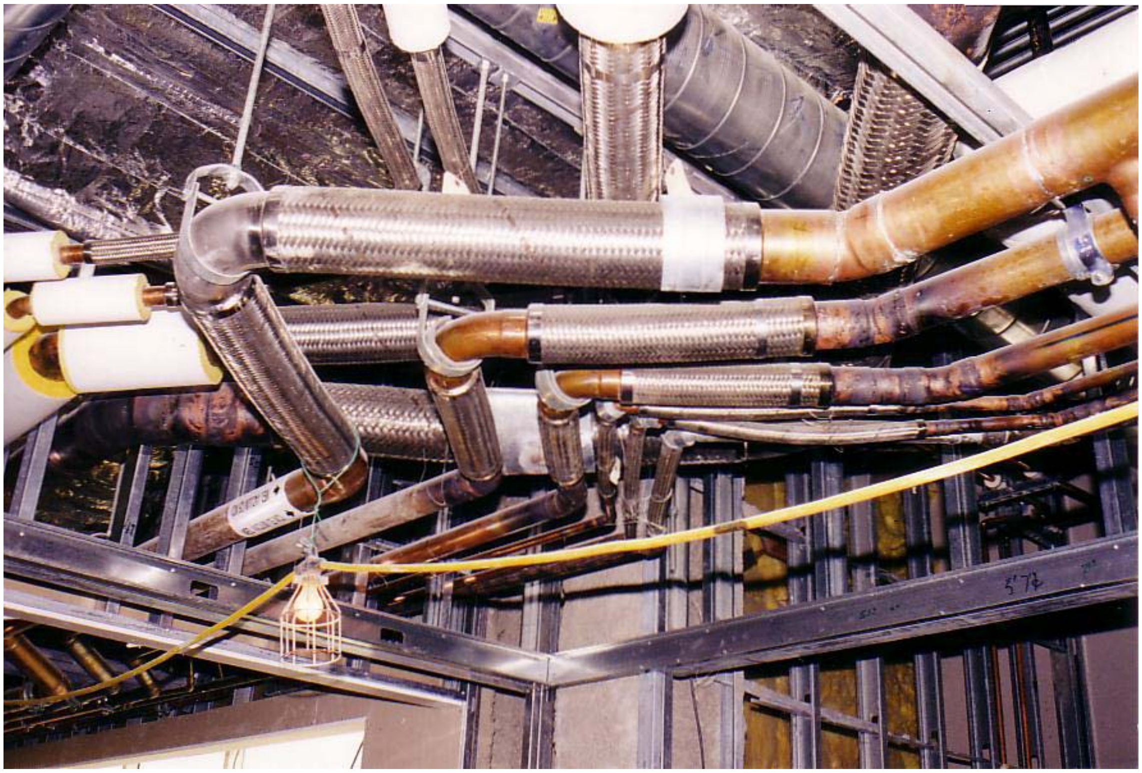


Figure 6.4.3.3-5 Flexible pipe connections at building separation (Photo courtesy of Mason Industries).

Mitigation Details

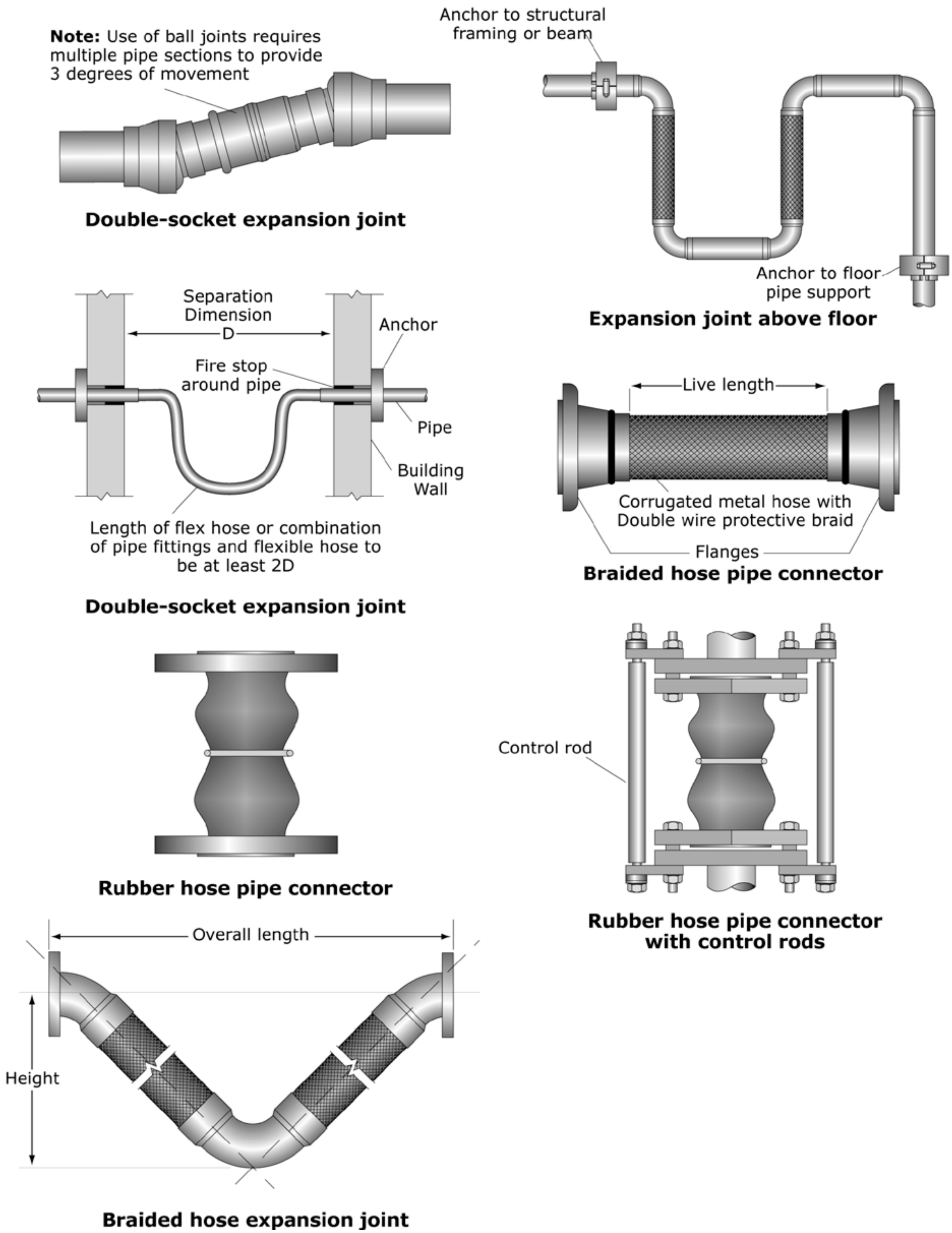


Figure 6.4.3.3-6 Flexible connections and expansion joints (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.4 PIPE RISERS

This category covers pipe risers for pressure piping, that is, vertical runs of pressurized piping such as those used in multistory buildings. Risers are typically supported by a combination of wall-mounted supports and additional floor-mounted or roof-mounted supports at the locations of penetrations. Due to their length, thermal movement may be an important consideration and seismic restraints must be designed to accommodate the anticipated inter-story drift and the thermal movement.

TYPICAL CAUSES OF DAMAGE

- Pipe risers must be designed to accommodate inter-story drift between adjacent floors, that is, differential movement between the points of support located on different floors of the building. If the pipe supports are not designed to accommodate this movement during an earthquake, the supports may fail or the pipes or pipe joints may fail and leak. Improperly supported pipes can become dislodged and fall; unbraced risers can sway and impact adjacent items.
- Pipes are vulnerable at penetrations, thus floor and roof penetrations must be sufficiently oversized to prevent impact. Unrestrained movement of pipes at penetrations may damage the piping and pipe restraints but may also damage flooring, ceilings, partitions, insulation, fire-proofing or other architectural finishes. For insulated risers, the piping insulation may also be damaged if the pipe chafes at the restraint. If risers are mounted to lightweight partitions, the partitions may be damaged unless they have been designed and braced to resist the piping loads.
- Because risers often involve very long pipe runs, the thermal movement may be significant. Unless seismic restraints are designed to accommodate thermal movement, the piping, pipe joints or rigid seismic restraints could be damaged under operating conditions and fail to perform properly in an earthquake.
- Pipe risers in multistory buildings are typically located in utility shafts or pipe chases; thus, they usually do not pose a significant falling hazard to occupants but riser damage could cause significant leakage resulting in property losses and business outage.

Damage Examples

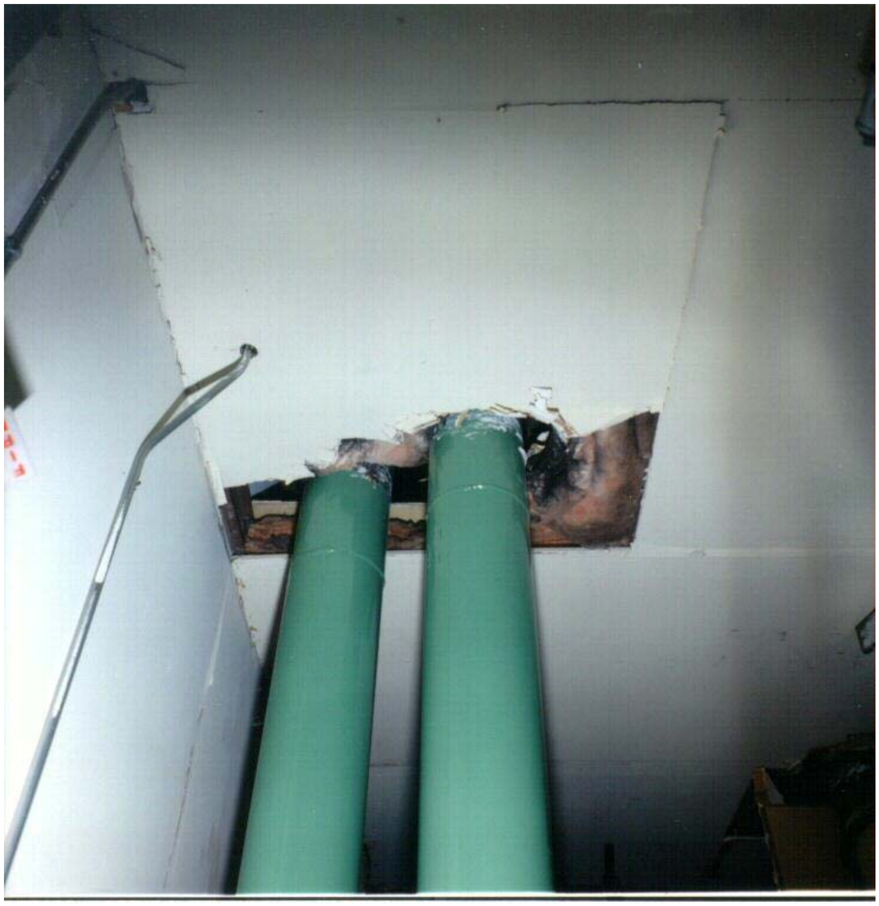


Figure 6.4.3.4-1 Movement of unbraced risers damaged ceiling finishes and insulation in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

SEISMIC MITIGATION CONSIDERATIONS

- See the general discussion of pipe bracing in Section 6.4.3.1.
- Standard steel pipe expands or contracts at a rate of 0.8 inch per 100 feet per 100 degrees Fahrenheit; supports and bracing for tall risers or piping subject to large temperature variations must be explicitly designed to accommodate thermal movement. Riser details for chilled water piping may need to accommodate additional insulation. Riser calculations should be performed assuming the full weight of water is at the bottom of the pipe riser.
- Pipe risers require vertical support (longitudinal restraints) as well as lateral bracing. Risers are typically supported and braced by a combination of wall-mounted restraints and floor- or roof-mounted supports or guides at the locations of penetrations. They

may also be supported by hangers located on horizontal branch lines within 24 inches of the centerline of the riser. Suspended support details are sometimes used at the top of the riser. The pipes may be rigidly mounted, for instance at the base of the riser, or mounted with elastomeric pads, sliding guides or vibration isolation. Specially designed riser clamps are often used to provide vertical support for pipe risers. Isolated piping should be supported independently from rigidly braced piping; rigid pipe attachments to lightweight walls may cause vibration problems under operating conditions.

- All vertical risers should have lateral restraints at the top and bottom of the riser and at each intermediate floor at a maximum spacing of 30 foot intervals. When installed as a riser, nonductile piping, such as no-hub cast iron piping, should include joint stabilizers where the joints are unsupported between floors.
- Pipe penetrations through structural elements such as beams, walls, and slabs must be coordinated with a structural engineer. Pipe penetrations through nonstructural walls, architectural finishes or roof membranes must be coordinated with an architect. Riser penetrations may require thermal insulation, fire proofing, sound proofing or weather proofing and unless properly detailed, these architectural and safety features may be compromised during an earthquake. See Section 6.4.3.8 for additional information about detailing pipe penetrations.

Mitigation Examples

Figure 6.4.3.4-2 Riser supports provide lateral restraint with vertical sliding guides that allow thermal movement; restraint hardware consisting of tube sections is welded to either side of pipe (Photo courtesy of Mason Industries).

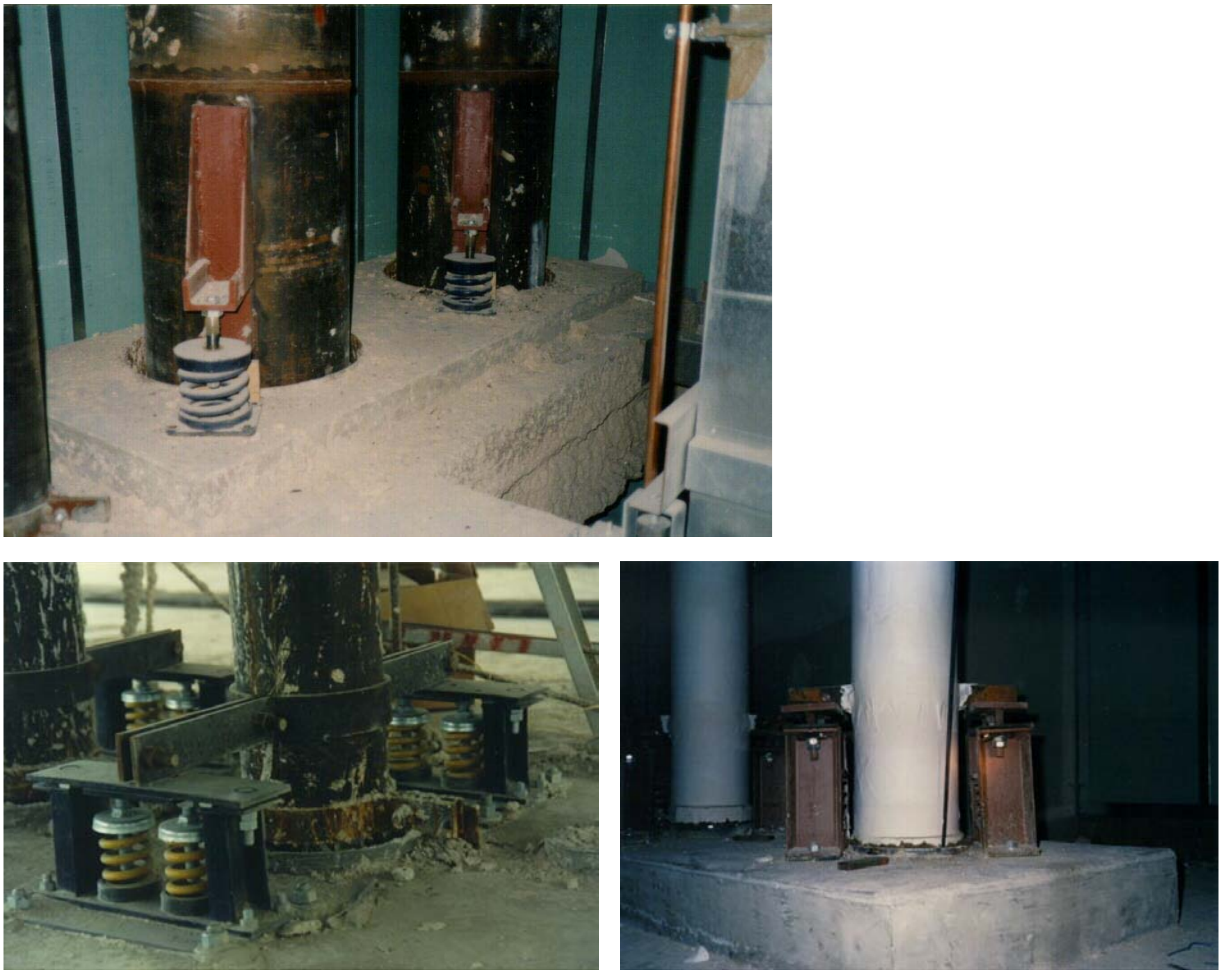


Figure 6.4.3.4-3 Different schemes for riser supports at floor penetrations with vibration isolation: first one with restraint hardware welded to pipe, second with two sets of riser clamps, and third with riser clamp inside the insulation (Photos courtesy of Mason Industries).

Figure 6.4.3.4-4 Insulated boiler pipe risers with welded lugs (small pipe sections) which travel vertically in guides providing lateral seismic restraint (Photo courtesy of Eduardo Fierro, BFP Engineers).

Mitigation Details

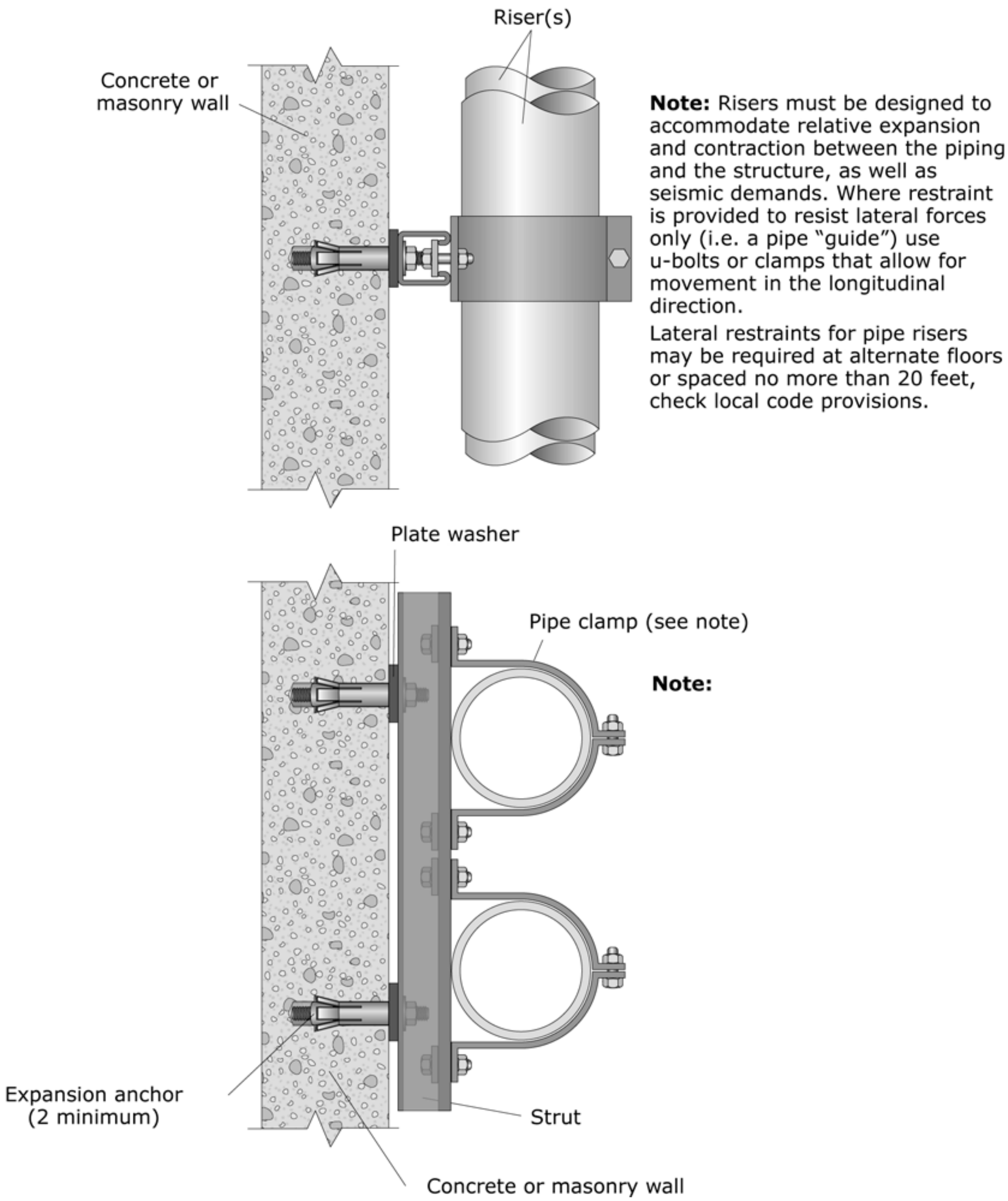


Figure 6.4.3.4-5 Wall-mounted pipe riser restraint/support (ER).

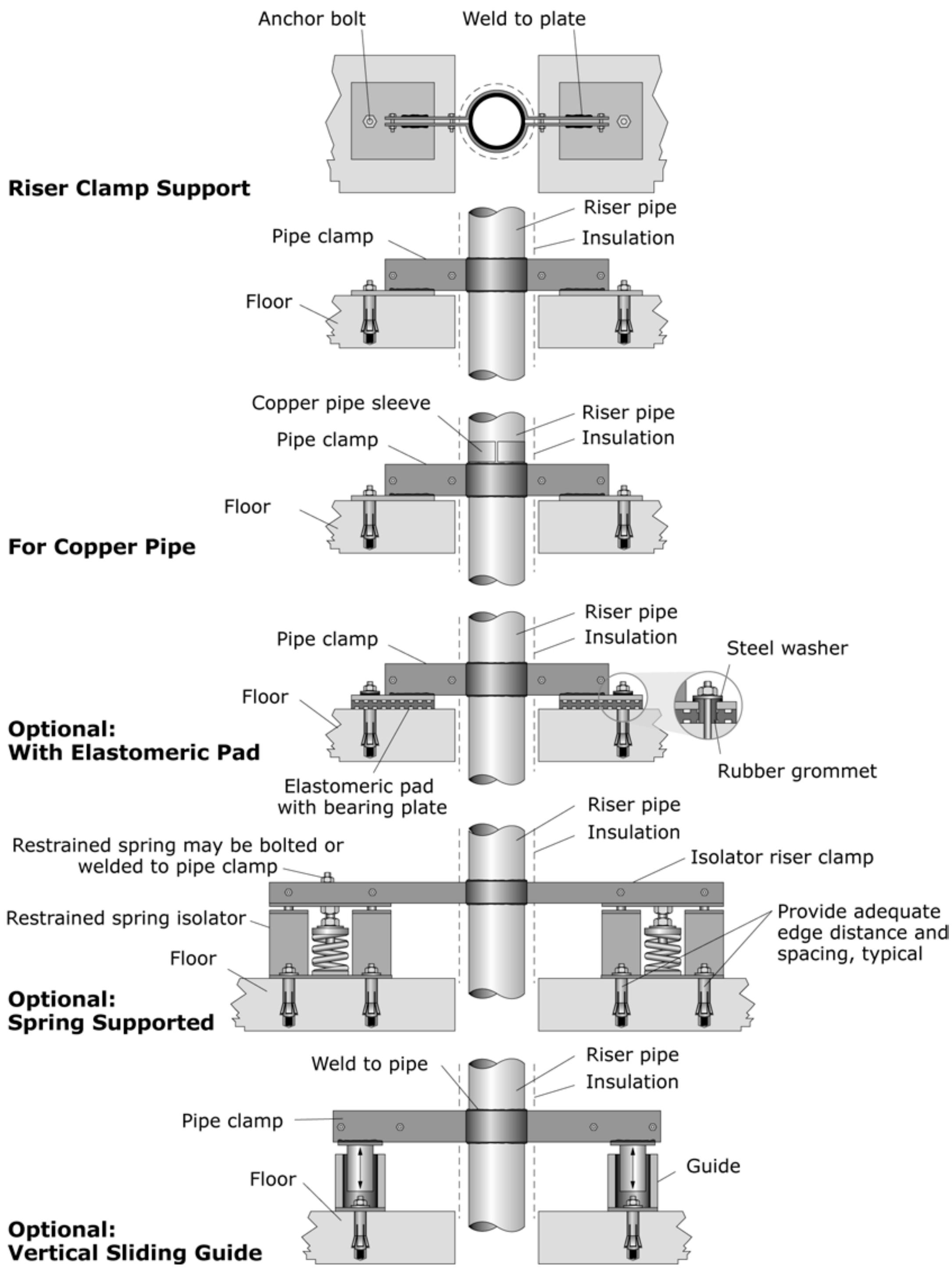


Figure 6.4.3.4-6 Riser restraint/support at floor penetrations – variations with pipe clamp, vibration isolation, and sliding guides (ER).

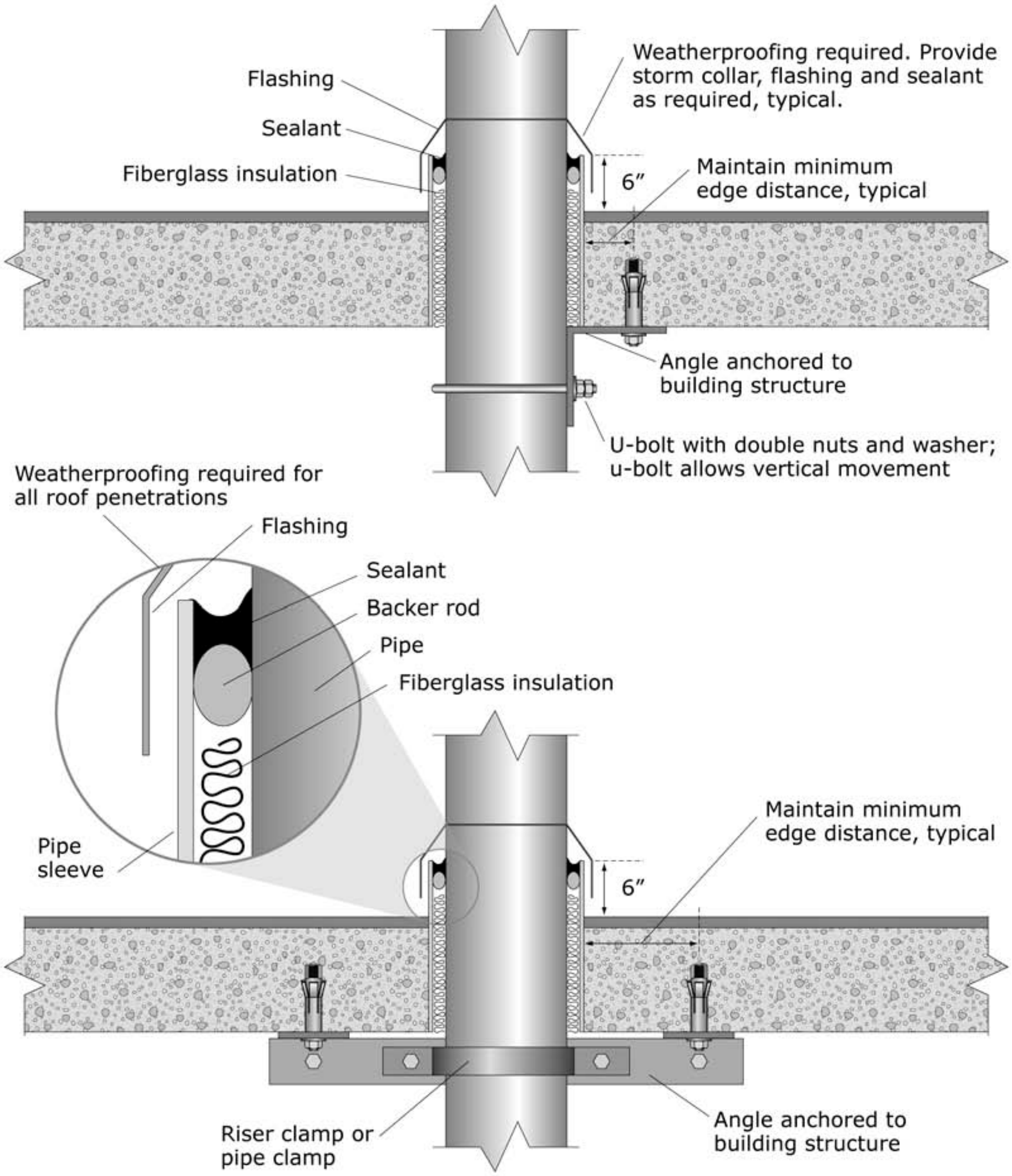


Figure 6.4.3.4-7 Riser restraint/support at roof penetration – variations with U-bolt or pipe clamp (ER).

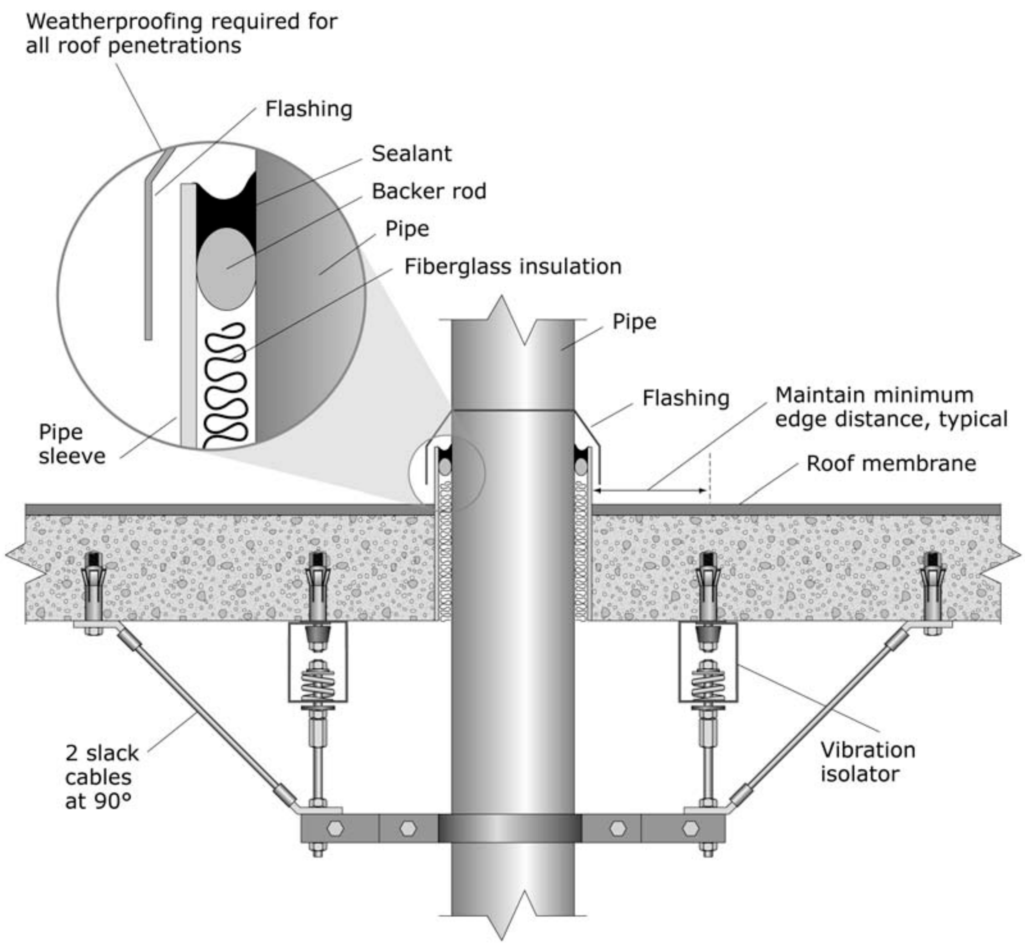


Figure 6.4.3.4-8 Roof penetration with vibration isolation (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.5 FLOOR-MOUNTED SUPPORTS

This category covers floor-mounted supports for pressure piping. Floor-mounted supports may be used to support either horizontal or vertical pipe runs with or without vibration isolation, either indoors or outdoors. Floor-mounted supports typically involve steel shapes anchored to structural framing or a structural concrete slab. These supports may have one cantilevered support member, one propped cantilever member, or be built up of multiple elements to form a trapeze or braced frame.

TYPICAL CAUSES OF DAMAGE

- Failure of pipe supports may result in damage to the support in question, damage to adjacent supports which are overloaded due to the initial failure, damage to the piping or pipe joints, damage to insulation, leakage of the contents, and outage of the system that the pipes support. Joints may fail if the layout of the seismic restraints is poor or where the restraints are inadequate for the anticipated forces and displacements. Piping damage may occur at building separations, seismic joints, or penetrations if the piping has not been detailed to account for the differential movement.
- Several failure mechanisms exist for floor-mounted supports: failure at base if anchorage is undersized, yielding of cantilever elements causing excessive deflection, and buckling of braced elements if braces are undersized.
- Unrestrained piping supported directly on the floor is vulnerable to damage due to excessive movement. Section 6.4.3.8 provides more information about potential damage at pipe penetrations.
- Low lying piping, regardless of the mounting details, is vulnerable to damage due to items falling from above. Pipes may be knocked loose or crushed if heavy items fall on them.

Damage Examples

Figure 6.4.3.5-1 Pipe and support assembly seem intact but photo shows evidence of longitudinal movement of the pipe in the U-bolts (Photo courtesy of BFP Engineers). A rubber pad was installed between the U-bolt and pipe in order to increase the friction coefficient, but was not sufficient to provide longitudinal restraint.

Figure 6.4.3.5-2 Damage to piping, stud wall and finishes due to movement of poorly restrained floor-mounted piping in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries).

SEISMIC MITIGATION CONSIDERATIONS

- Horizontal and vertical pipe runs need vertical, lateral, and longitudinal restraints. Floor-mounted supports can be used to provide restraint for any combination of these loads, can be designed for many different configurations, may be used with or without vibration isolation, and may be used either indoors or outdoors.
- Longitudinal restraints require positive support to the pipe with a pipe clamp or welded lug; U-bolts do not provide sufficient longitudinal restraint, as observed in Figure 6.4.3.5-1. For insulated piping, longitudinal restraint hardware may need to be located beneath the insulation in order to prevent longitudinal slip.
- In an existing concrete slab, care must be taken to locate rebar or post-tensioned tendons prior to drilling holes for anchor bolts. If the base plate for the pipe support is near the edge of a concrete curb or slab, care must be taken to provide sufficient edge distance and embedment for the anchor bolts. Some types of anchors are not recommended for use with vibratory loads. FEMA 414, *Installing Seismic Restraints for*

Duct and Pipe (2004) provides additional precautions regarding the installation of anchor bolts and general guidance on pipe restraints.

Mitigation Examples

Figure 6.4.3.5-3 Floor-mounted supports for insulated pipe with vibration isolation (Photo courtesy of Mason Industries).

Figure 6.4.3.5-4 Floor/ground-mounted supports for industrial piping in Chile; piping undamaged in the 2010 magnitude-8.8 Chile Earthquake. Pipe supports include concrete pedestal, base plate, and built-up welded support stand. (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

Figure 6.4.3.5-5 Floor-mounted supports for industrial piping in Chile; piping undamaged in the 2010 Chile Earthquake. The Chilean Industrial Code (Norma Chilena 2369) requires that shear forces be resisted by shear keys as shown; lower photo is detail of piping at upper right (Photos courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

Mitigation Details

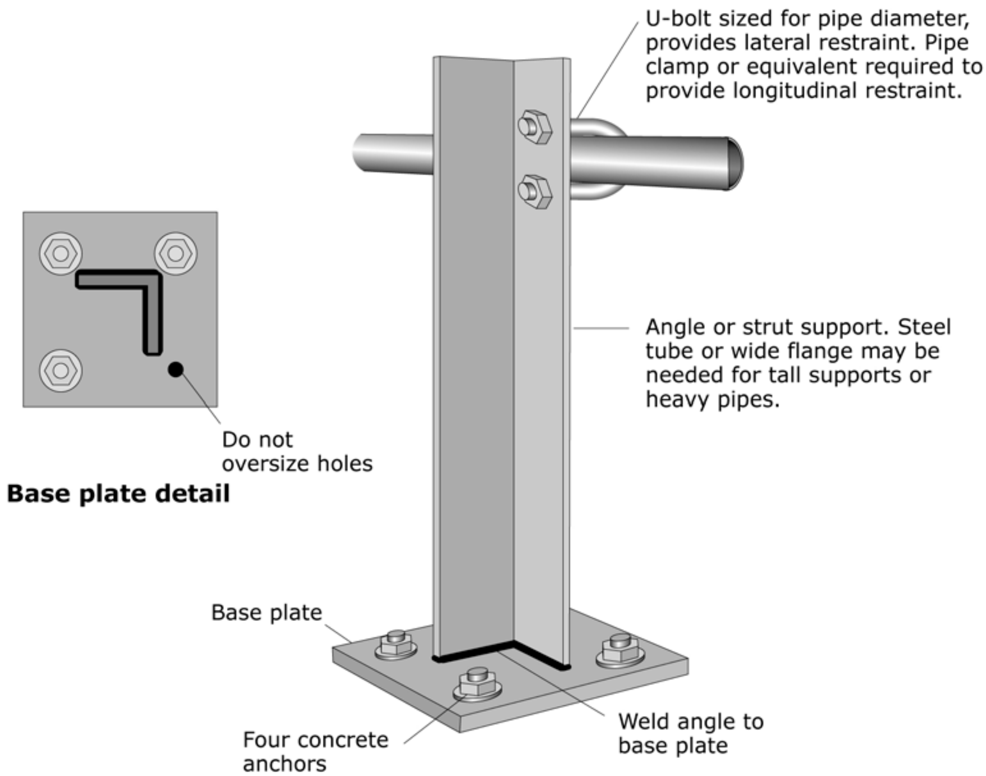


Figure 6.4.3.5-6 Floor-mounted single vertical pipe support (ER).

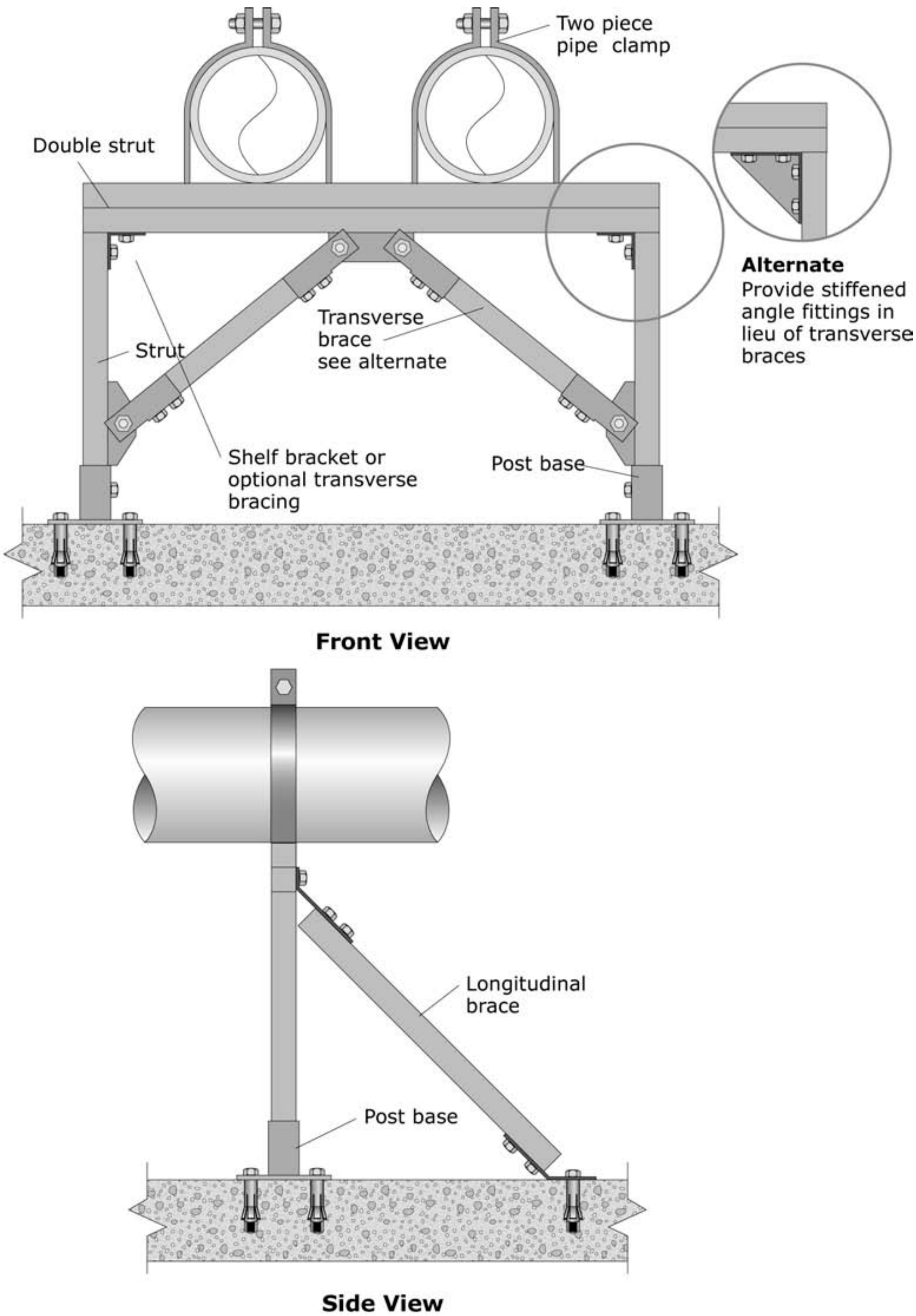


Figure 6.4.3.5-7 Floor-mounted pipe stand (strut frame) (ER).

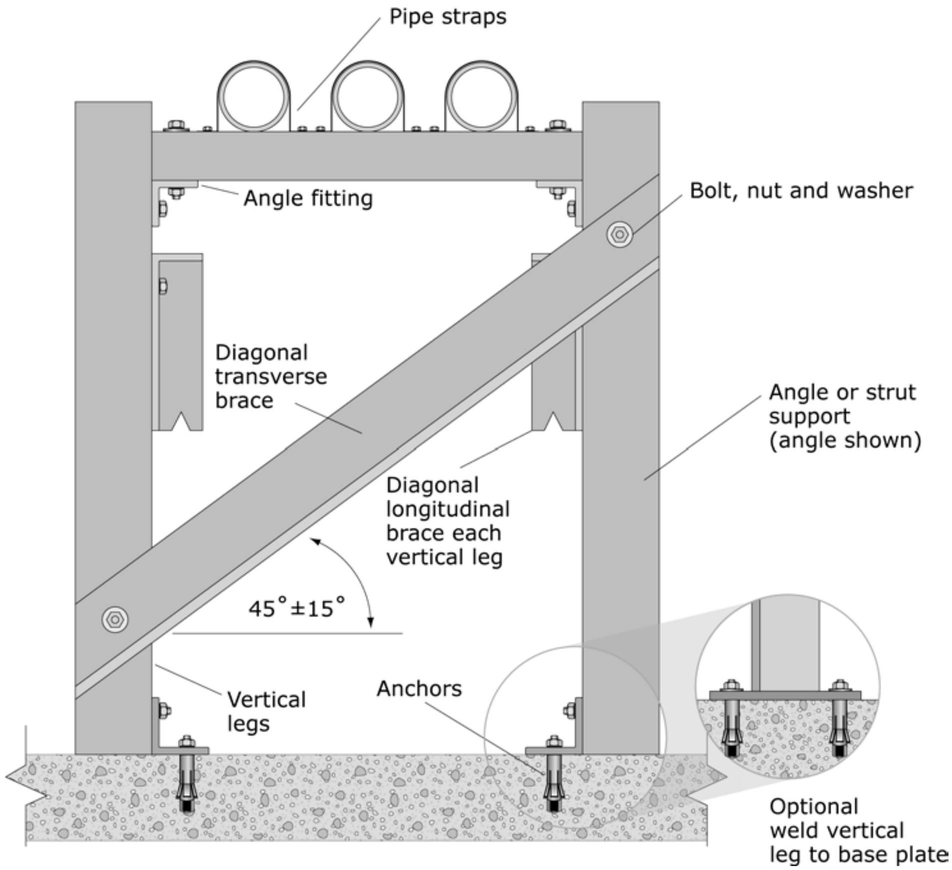


Figure 6.4.3.5-8 Floor-mounted pipe stand (steel shapes) (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.6 ROOF-MOUNTED SUPPORTS

This category covers roof-mounted supports for pressure piping. Roof-mounted supports may be used to support either horizontal or vertical pipe runs. Roof-mounted supports consist of wood blocking or steel shapes anchored to structural framing or a structural concrete slab and may be mounted with or without vibration isolation. These supports may be flush with the roof surface, have one cantilevered support member, one propped cantilever member, or be built up of multiple elements to form a trapeze or braced frame.

TYPICAL CAUSES OF DAMAGE

- Failure of pipe supports may result in damage to the support in question, damage to adjacent supports which are overloaded due to the initial failure, damage to the piping, damage to insulation or roofing, leakage of the contents, and outage of the system that the pipes support. Joints may fail if the layout of the seismic restraints is poor or where the restraints are inadequate for the anticipated forces and displacements. Piping damage may occur at locations where piping runs across roof separations or seismic joints if the piping has not been detailed to account for the differential movement.
- Seismic accelerations are often highest at the roof level and thus roof-mounted items are particularly vulnerable to failure unless properly designed. Several failure mechanisms exist for roof-mounted supports: failure at base if anchorage is undersized, yielding of cantilever elements causing excessive deflection, and buckling of braced elements if braces are undersized.
- Unrestrained piping supported directly on the roof is vulnerable to damage due to excessive movement. Unanchored wood sleepers may overturn or slide.
- Damage to roof-mounted items may also result in damage to the roofing membrane causing subsequent water damage.

Damage Examples

Figure 6.4.3.6-1 Damaged supports and piping on roof-mounted HVAC unit in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries). Both the roof-mounted wood sleepers and strut supports failed.

Figure 6.4.3.6-2 Unrestrained wood sleepers on roof-mounted piping slid a foot in either direction in 2010 magnitude-6.5 Eureka Earthquake (Photos courtesy of Maryann Phipps, Estructure).

Figure 6.4.3.6-3 Unrestrained roof-mounted piping broke at the connection to the equipment in the 2010 Eureka Earthquake. Piping mounted on wood sleepers should typically be restrained to the roof, not free to slide (Photo courtesy of Maryann Phipps, Estructure).

SEISMIC MITIGATION CONSIDERATIONS

- Pipe runs need vertical, lateral and longitudinal restraints. Roof-mounted supports can be used to provide restraint for any combination of these loads, can be designed for many different configurations, and may be used with or without vibration isolation. Longitudinal restraints require positive support to the pipe with a pipe clamp or welded lug; U-bolts do not provide effective longitudinal restraint.
- Seismic accelerations are often highest at the roof level; roof-mounted supports may need to be more robust than those located elsewhere in a building. They additionally need to be protected from corrosion and deterioration or they will be ineffective during an earthquake.
- In an existing concrete roof slab, care must be taken to locate rebar or post-tensioned tendons prior to drilling holes for anchor bolts. If the base plate for the pipe support is near the edge of a concrete curb or slab, care must be taken to provide sufficient edge distance and embedment for the anchor bolts. Some types of anchors are not

recommended for use with vibratory loads. FEMA 414, *Installing Seismic Restraints for Duct and Pipe* (2004) provides additional precautions regarding the installation of anchor bolts.

- Weatherproofing is an important consideration for roof-mounted supports; any penetration of the roof membrane must be adequately sealed to prevent roof leakage. Refer to Section 6.4.3.8 for additional discussion of pipe penetrations.
- Seismic restraint hardware for any exterior exposure should be specified using materials or coatings to reduce corrosion and may require periodic painting or replacement to maintain the effectiveness of the restraint. Items exposed to salt air, or deicing compounds such as in a parking structure, may be especially at risk.

Mitigation Examples

Figure 6.4.3.6-4 Roof-mounted supports with vibration isolation (Photo courtesy of Mason Industries).

Mitigation Details

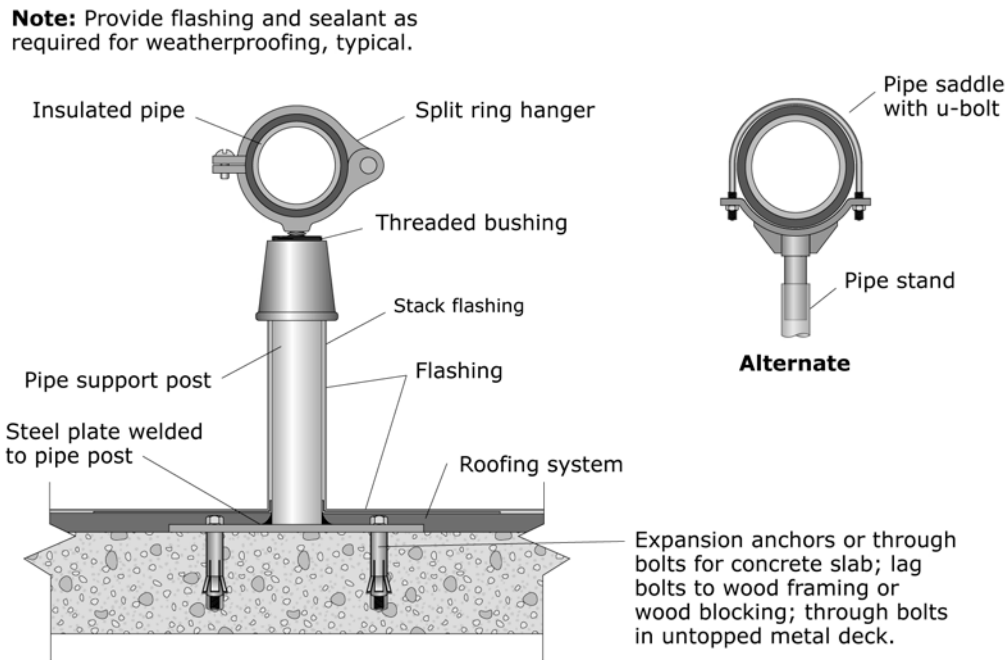
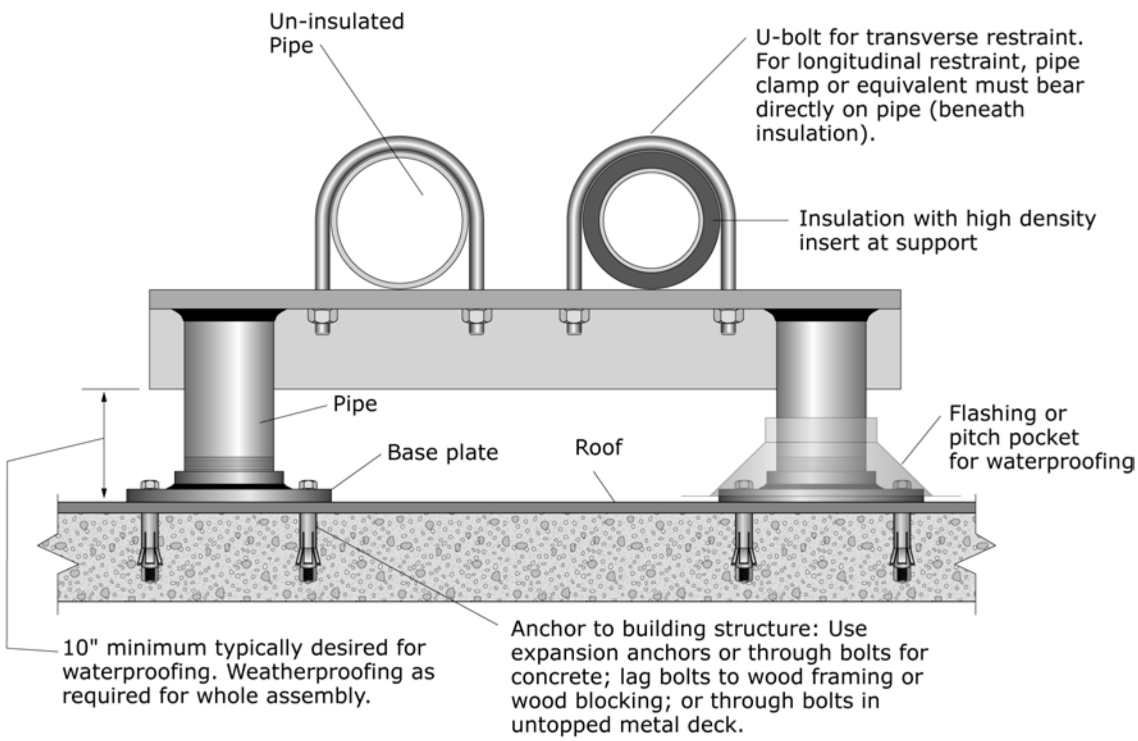


Figure 6.4.3.6-5 Roof-mounted single vertical pipe support (ER).



Note: Provide flashing and sealant as required for weatherproofing, typical.

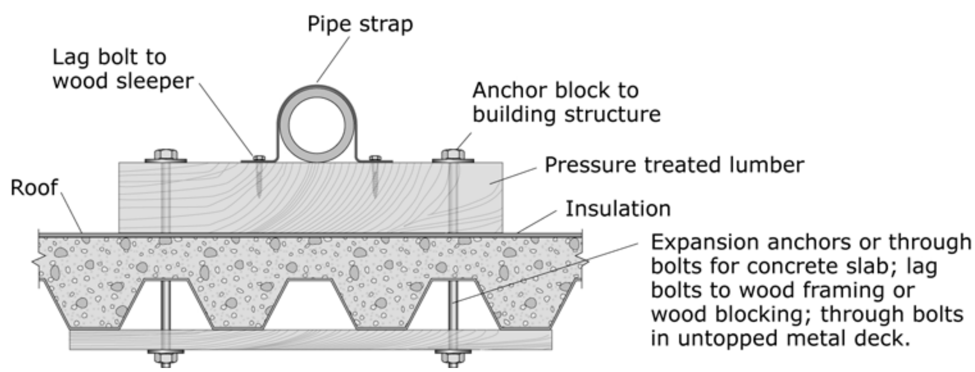


Figure 6.4.3.6-6 Roof-mounted pipe stand (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.7 WALL-MOUNTED SUPPORTS

This category covers wall-mounted supports for pressure piping. Wall-mounted supports may be used to support either horizontal or vertical pipe runs, may be used with or without vibration isolation, and may be used either indoors or outdoors. Wall-mounted supports may be mounted flush or be built up out of assemblies of steel shapes anchored to structural framing or a structural wall.

TYPICAL CAUSES OF DAMAGE

- Failure of pipe supports may result in damage to the support in question, damage to adjacent supports which are overloaded due to the initial failure, damage to the piping or pipe joints, damage to insulation, leakage of the contents, and outage of the system that the pipes support.
- Joints may fail if the layout of the seismic restraints is poor or where the restraints are inadequate for the anticipated forces and displacements. Piping damage may occur at building separations or seismic joints if the piping has not been detailed to account for the differential movement. Wall-mounted piping often passes thru penetrations; piping may be vulnerable unless the penetrations are properly detailed.
- Several failure mechanisms exist for wall-mounted supports: failure at wall plate if anchorage is undersized, yielding of cantilever elements causing excessive deflection, and buckling of braced elements if braces are undersized. Piping attached to nonstructural walls or walls of insufficient strength may also result in damage to the wall or partition and the architectural finishes or fire-proofing.

Damage Examples

Figure 6.4.3.7-1 Wall-mounted supports for horizontal and vertical pipe runs with exterior exposure. Photo shows minor damage at wall penetration of green pipe and minor movement at some U-bolts, but restraints generally performed well (Photo courtesy of Eduardo Fierro, BFP Engineers). Note that lateral restraint near an elbow can be used to provide longitudinal restraint for a perpendicular pipe run.

Figure 6.4.3.7-2 Pipe supports attached to wall of damaged silo (Photo courtesy of Eduardo Fierro, BFP Engineers). In spite of structural damage to silo, cast-in-place pipe supports were still intact and the piping did not fall.

SEISMIC MITIGATION CONSIDERATIONS

- Horizontal and vertical pipe runs need vertical, lateral and longitudinal restraints. Wall-mounted supports can be used to provide restraint for any combination of these loads, can be designed for many different configurations, may be used with or without vibration isolation, and may be used either indoors or outdoors. Pipes may be mounted flush to the wall or offset; make sure to check that the wall or partition is capable of carrying the piping loads and will not develop vibration problems.
- Longitudinal restraints require positive support to the pipe with a pipe clamp or welded lug; U-bolts do not provide sufficient longitudinal restraint. For insulated piping, longitudinal restraint hardware may need to be located beneath the insulation in order to prevent longitudinal slip.
- In an existing concrete or masonry wall, care must be taken to locate rebar prior to drilling holes for anchor bolts so the rebar is not cut. Anchorage for isolated piping should be independent of anchorage for rigidly mounted pipe. In addition, some types of anchors are not recommended for use with vibratory loads. FEMA 414, *Installing Seismic Restraints for Duct and Pipe* (2004), provides additional precautions regarding the installation of anchor bolts and general guidance on pipe restraints.

Mitigation Examples

Figure 6.4.3.7-3 Wall-mounted pipe restraint examples using standard strut shapes and connectors (Photo courtesy of Cynthia Perry, BFP Engineers). Bottom view still under construction; pipes temporarily attached with plastic ties.

Mitigation Details

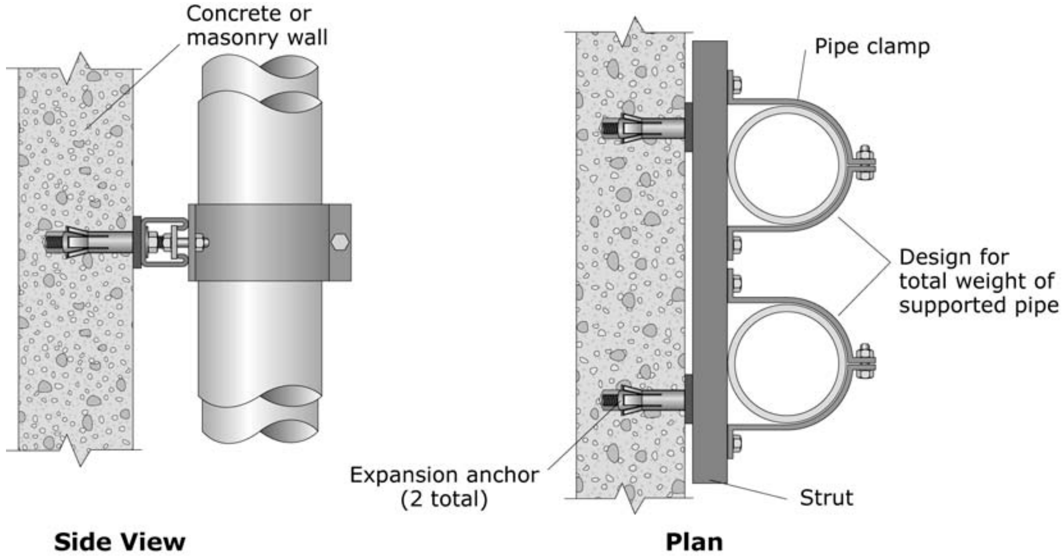


Figure 6.4.3.7-4 Surface-mount to structural wall (ER).

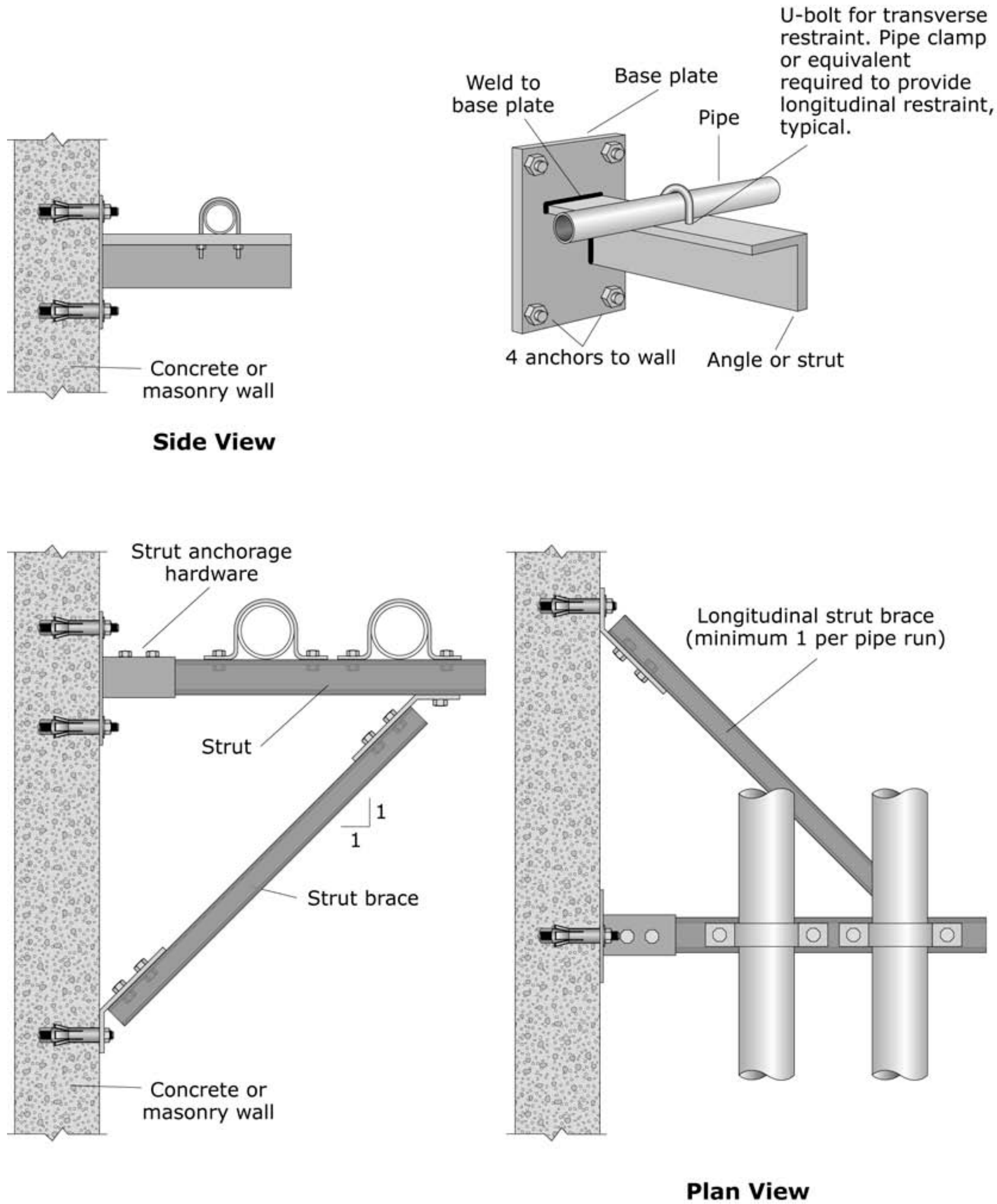


Figure 6.4.3.7-5 Wall-mount with steel shape or struts welded to concrete wall (ER).

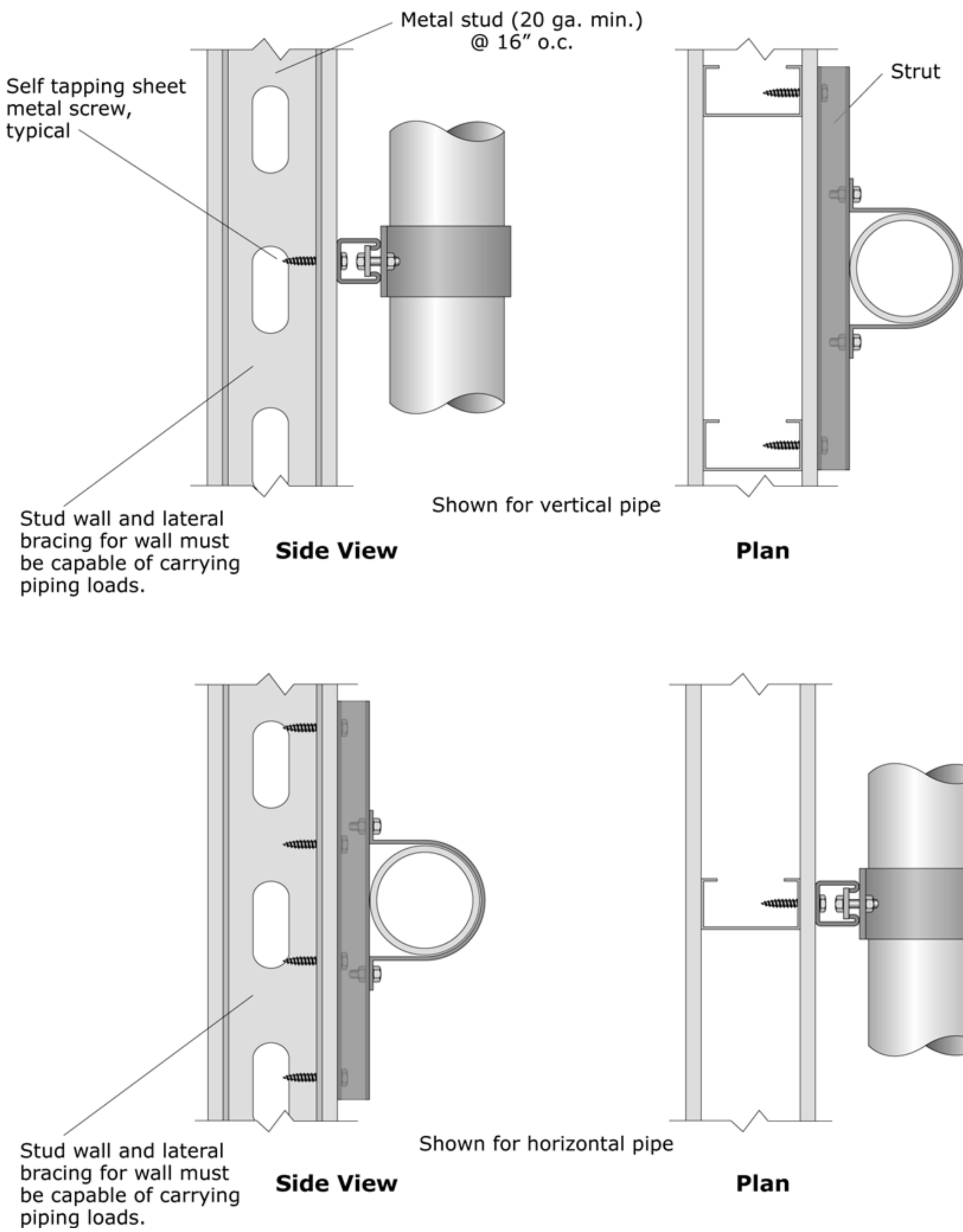


Figure 6.4.3.7-6 Wall-mount using strut channels to metal stud wall (ER).

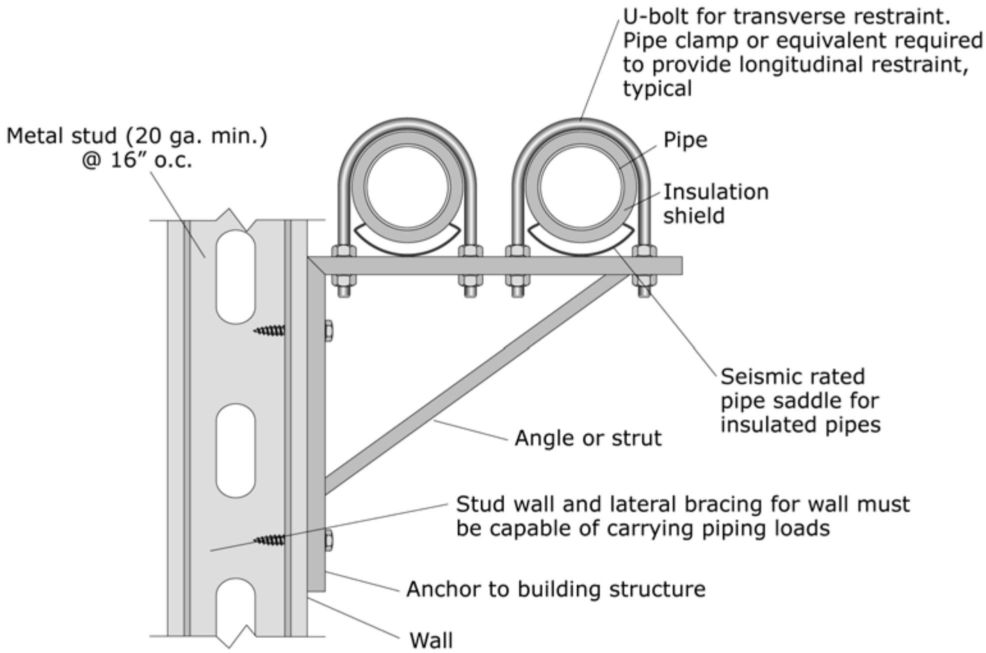


Figure 6.4.3.7-7 Wall-mount to stud wall with pre-manufactured brackets (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.3 PRESSURE PIPING

6.4.3.8 PENETRATIONS

This section addresses locations where pressure piping passes through floor, roof, or wall penetrations in either architectural or structural components. Penetrations usually fall into one of three categories: 1) the penetration is sufficiently oversized to prevent impact between the pipe and surrounding wall or slab; 2) a seismic restraint is located at or near the penetration so the pipe and surrounding wall or slab are constrained to move together; or 3) the penetration is not properly detailed and becomes an unintended restraint in the piping run which may result in damage to the piping, wall, slab, or finishes. Structural and nonstructural elements may require strengthening around penetrations or may need special detailing to provide fire-proofing, sound-proofing, and weather-proofing or improve the appearance of architectural finishes.

TYPICAL CAUSES OF DAMAGE

- Pipe movement at penetrations often results in damage to architectural finishes, fire-proofing, and insulation. Failure of joints at or near penetrations may result in leakage causing further damage to these components.
- Where pipes pass through unreinforced masonry walls, the opening may create a point of weakness resulting in crack propagation from the opening. Lightweight partitions or ceilings are also frequently damaged by movement of unrestrained piping. Pipe movement at penetrations may also result in damage to electrical lines in the wall or ceiling space.

Damage Examples

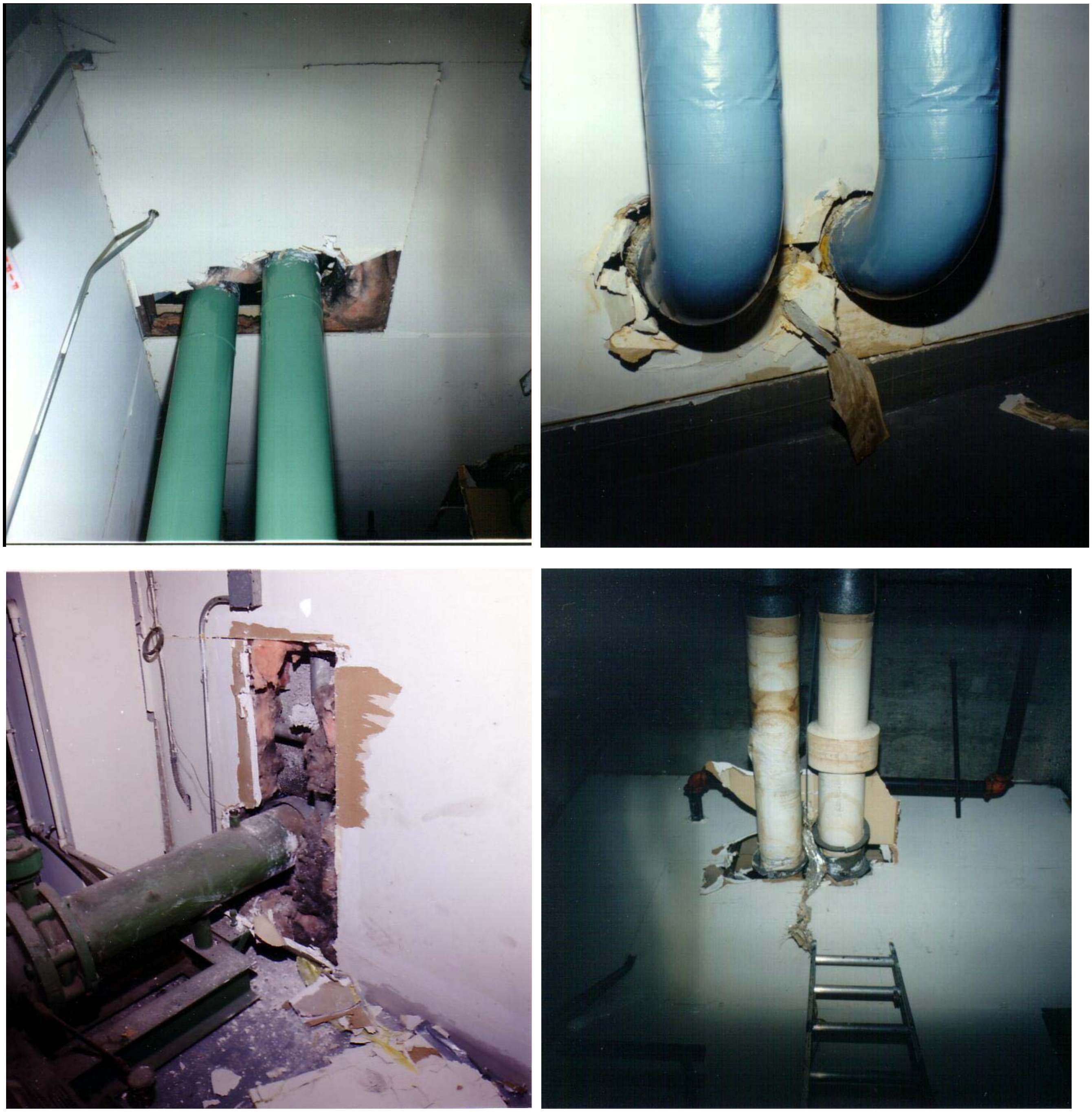


Figure 6.4.3.8-1 Damage to ceilings, gypsum board partitions, fire-proofing, and insulation in the 1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of Mason Industries). Note that the blue piping has joints located in the wall space which leaked, resulting in additional damage.

Figure 6.4.3.8-2 Exterior stucco damage at wall penetration for fire protection piping in the 2001 magnitude-8.4 Peru Earthquake (Photos courtesy of Eduardo Fierro, : BFP Engineers).

Figure 6.4.3.8-3 Wall penetrations for piping and ducts contributed to damage to unreinforced masonry walls at an industrial facility in the 2010 magnitude-7 Haiti Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers). The piping and ducts were not damaged but the walls cracked and will need to be repaired.

SEISMIC MITIGATION CONSIDERATIONS

- As described above, there are two different approaches for avoiding damage at pipe penetrations. Either the penetration should be designed to be oversized to avoid contact between the pipe and the wall or slab, or the pipe should be restrained at or near the penetration so the pipe and wall or slab are constrained to move together.
- Penetrations should be oversized wherever possible to allow for differential movement of pipe supports and the structural elements they are attached to on either side of the wall, floor, or roof slab. Alternatively, lateral restraints for the piping should be provided close to the penetration to prevent impact between the pipe and the opening. Where piping crosses from one building to another, flexible connections may also be required near the penetration.
- Pipes often fail or leak at joints; pipe joints should be not be located within penetrations where they will leak into a wall cavity or are inaccessible for inspection and repair.
- Penetrations through structural walls, slabs, or framing must be coordinated with a structural engineer; structural walls, slabs, or framing elements may require strengthening around penetrations. For large openings such as a pipe chase, this may involve extra trim steel around the opening or additional framing members beneath a slab. Penetrations in a structural steel girder may require welded reinforcement plates around the opening. For locating penetrations in existing concrete or masonry walls or concrete slabs, care must be taken to locate rebar or post-tensioned tendons prior to drilling holes for pipe penetrations so these elements are not cut.
- Penetrations through nonstructural walls should be coordinated with an architect to ensure that fire-proofing, sound-proofing, weather-proofing, insulation requirements and finishes on either side of the opening are not compromised. Roof penetrations have particular issues related to weather-proofing and corrosion protection; care must be taken to avoid leakage at roof penetrations. Where penetrations pass through weak materials such as unreinforced masonry or lightweight partitions, these elements may require strengthening.
- Detailing at penetrations often involves several layers of material and finishes each of which require attention; penetrations through structural elements may involve both the engineer and the architect. For instance, a penetration through a masonry wall with interior plaster and exterior stucco will require detailing for all three of these materials. The damage shown in Figure 6.4.3.8-2 occurred because although the masonry penetration was oversized and filled with packing, the exterior stucco was placed flush with the pipe resulting in stucco damage during the earthquake.

- Pipe risers that pass through floor and roof penetrations must be detailed so the seismic restraints can also accommodate longitudinal thermal movement of the pipe. If allowance for thermal movement is not included in the design, the seismic restraints may be damaged under operating conditions and fail to perform properly in an earthquake.
- Penetrations in exit corridors needed for emergency egress may warrant special care; similarly, penetrations in boiler rooms or locations with fuel lines or hazardous materials may also warrant special detailing to maintain the fire-proofing of the space in the event of a post-earthquake fire.
- FEMA 414, *Installing Seismic Restraints for Duct and Pipe* (2004), provides additional precautions regarding the installation of anchor bolts and general guidance on pipe restraints.

Mitigation Examples

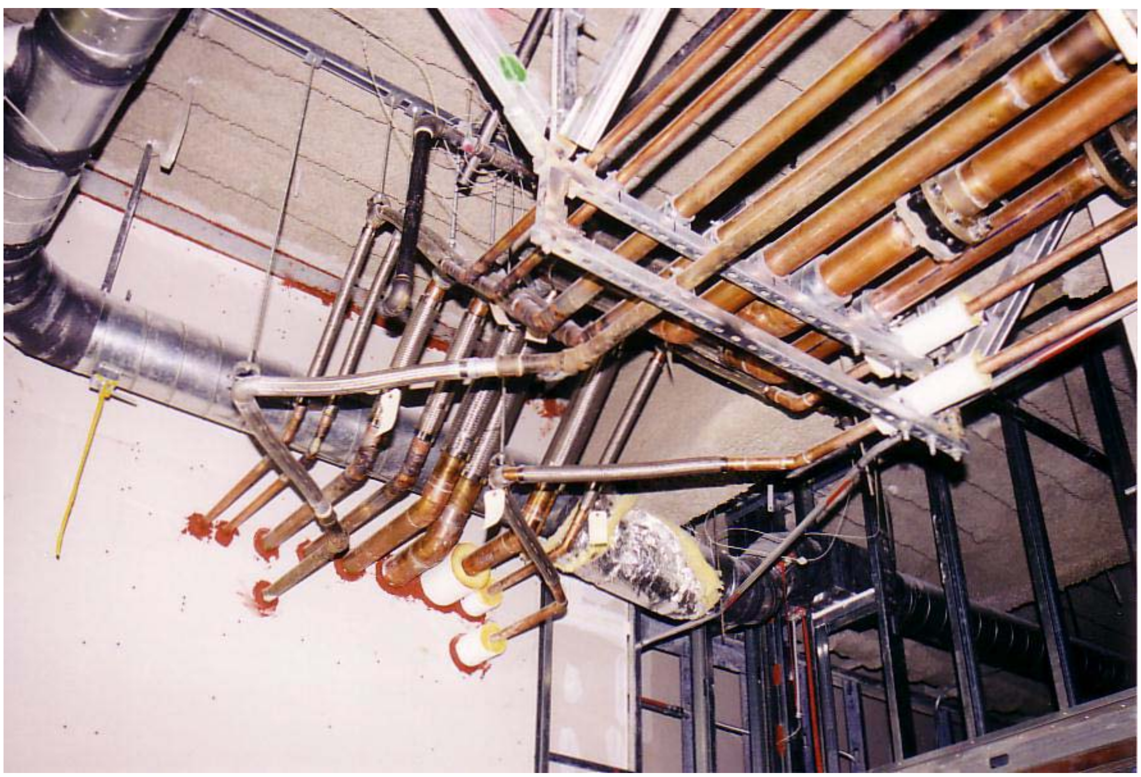


Figure 6.4.3.8-4 Wall penetrations with lateral restraints at trapeze in foreground, flexible couplings with independent vertical supports, and sealant at each wall penetration (Photo courtesy of Mason Industries).

Figure 6.4.3.8-5 Floor penetration with oversized opening and vertical and lateral restraints immediately above floor (Photo courtesy of Mason Industries).

Figure 6.4.3.8-6 Series of pipe penetrations through a full-height CMU partition wall. Note pipe suspended from floor above; partition anchored to floor below and detailed with steel clip angles intended to provide lateral restraint for the wall but allow relative slip between the wall and slab above. The hangers will move with the floor above and the pipe at penetration will move with the wall. Lateral restraints are located immediately above floor (Photo courtesy Cynthia Perry, BFP Engineers).

Mitigation Details

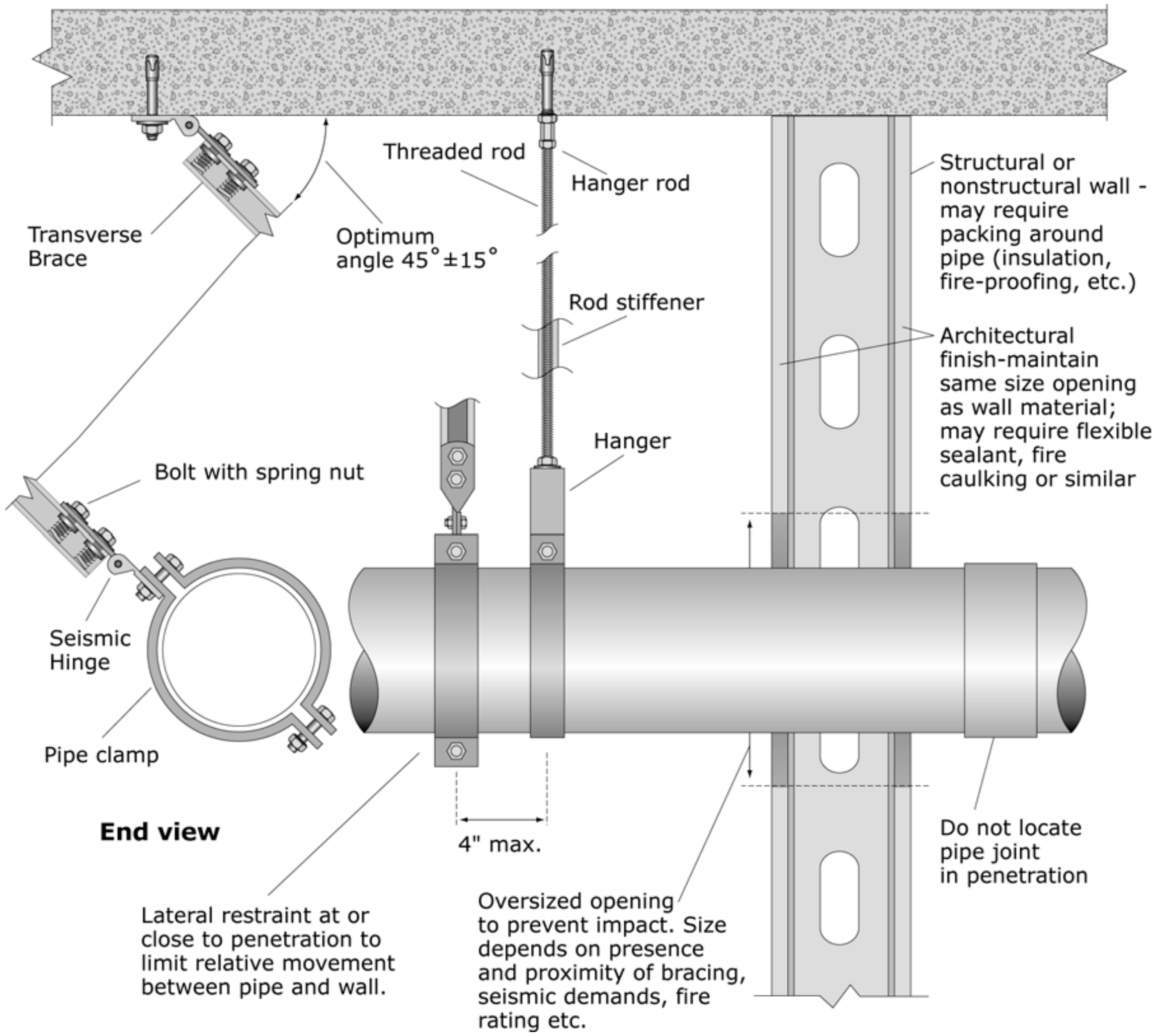


Figure 6.4.3.8-7 Wall penetration (ER).

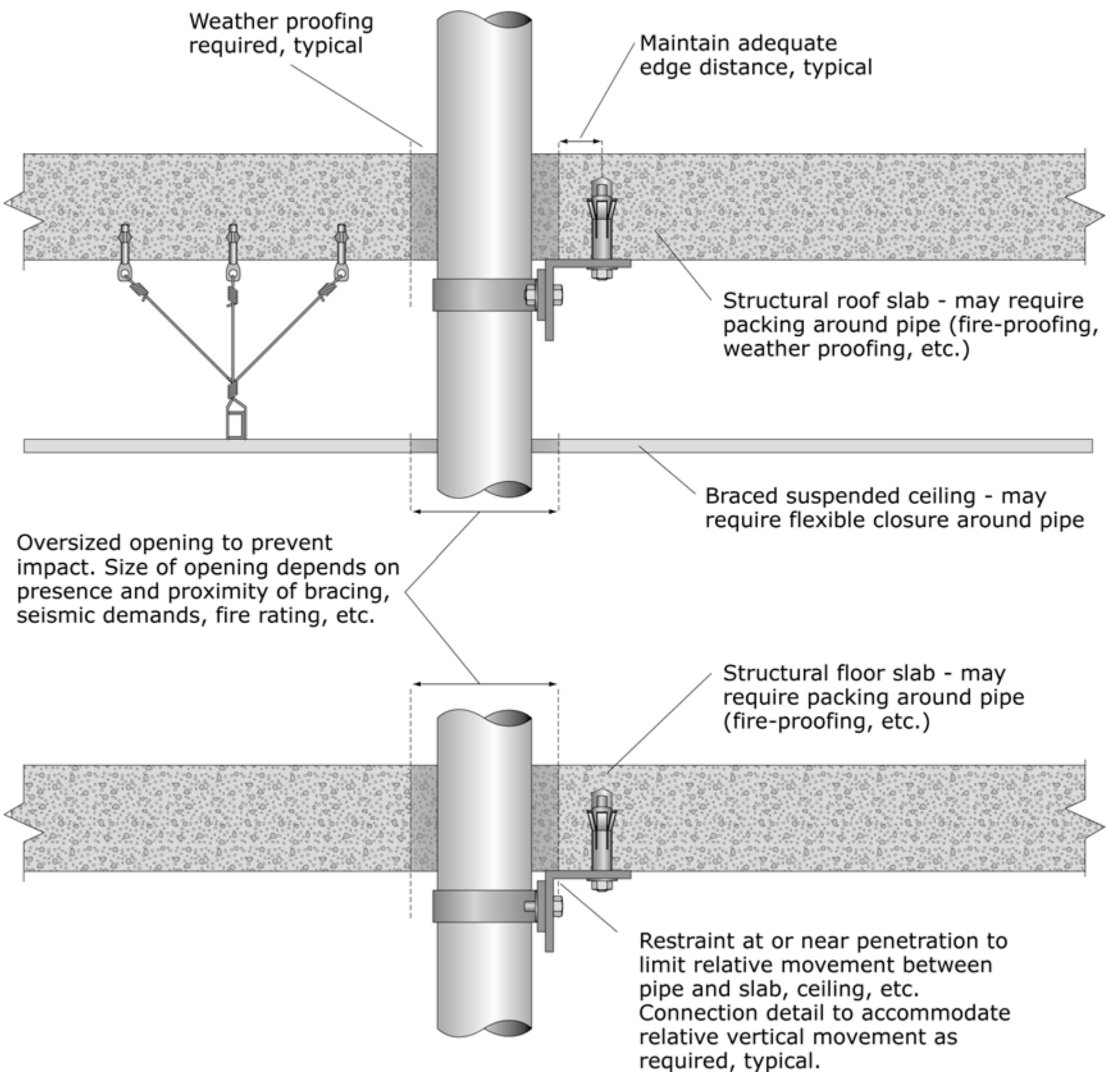


Figure 6.4.3.8-8 Floor or roof penetration (ER).